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Applications of Cost-Effectiveness Analysis to Air Pollution Control

Ernst and Ernst, Washington, D.C.

Prepared For
Consumer Protection & Environmental Health Service, Rockville, Md.

Apr 70

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Federal, state, and local air pollution control agencies are now starting to deal with the development of air quality standards, abatement implementation plans, pollution control codes, envorcement actions, manpower requirements and training, and the jurisdictional problems arising from the interurban, interstate, and international transport of pollution. Management decision techniques are urgently needed to provide a coherent framework for selecting action alternatives.

This report discusses some cost-effectiveness techniques developed and applied to aid in the selection of air pollution control alternatives.

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APPLICATIONS OF COST-EFFECTIVENESS ANALYSIS TO AIR POLLUTION CONTROL

Prepared for

U. S. Department of Health, Education, and Welfare
Public Health Service
Consumer Protection and Environmental Health Service

By
ERNST & ERNST
April, 1970

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CONTENTS

PAGE

Letter of Transmittal — iii

Section

I. Introduction and Summary — 1
II. Model City I Study — 3
III. Model City II Study — 27
IV. National Capital Area Study — 74
V. New York-New Jersey Study — 95
VI. Kansas City Study — 123
VII. Conclusions and Implications — 132

Appendix

A. MET Program Flow Diagram and Listing — 134
B. Model City II Study Program — 139
C. Methods of Estimating Annual Costs of Emission Control Alternatives — 181
D. CONCEN, AG, SORT, SORTCON, and INTCODE Program Listings and Flow Charts — 200
E. Factors Considered in Study — 226

ERNST & ERNST
1225 CONNECTICUT AVE., N. W.
WASHINGTON, D. C. 20036

April 30, 1970

Mr. Paul H. Gerhardt
Chief, Economic and Social
Analysis Section
Room 17-75
5600 Fishers Lane
Rockville, Maryland 20852

Dear Mr. Gerhardt:

We are pleased to submit our report entitled "Applications of Cost-Effectiveness Analysis to Air Pollution Control." This submission fulfills the requirements of Contract No. CPA22-69-17 Article IB(3) for a report summarizing the procedures, findings, and policy implications of previous model city studies so that these simulation techniques can be further explored to determine whether more widespread use can be made of them. Appropriate graphs, tables, formulae, contour maps, simplified flow charts, and source program listings of the computer programs are included in accordance with contract requirements.

Very truly yours,

Ernst + Ernst

I. INTRODUCTION AND SUMMARY

Federal, state, and local air pollution control agencies are now starting to deal with the development of air quality standards, abatement implementation plans, pollution control codes, enforcement actions, manpower requirements and training, and the jurisdictional problems arising from the interurban, interstate, and international transport of pollution. Management decision techniques are urgently needed to provide a coherent framework for selecting action alternatives.

This report discusses some cost-effectiveness techniques developed and applied to aid in the selection of air pollution control alternatives. The techniques were developed in several contract studies for the National Air Pollution Control Administration (NAPCA), U. S. Department of Health, Education, and Welfare. Bringing together the cost-effectiveness concepts, methods, and results of these studies allows their utility as tools of air resource management to be more readily evaluated.

REQUIREMENTS OF METHODOLOGY

The development of a methodology for analysis of air pollution abatement has been guided by several key requirements:

- The method must have application to a wide range of urban environments with different pollution sources, fuel use and cost structures, meteorology, and different abatement objectives.
- The method must be capable of generalization to accommodate abatement analysis of many different pollutants.
- The method must be useful immediately with present data and become increasingly more powerful as research provides more and better data concerning air pollution.
- The method must be useful at the Federal, state, and local levels for examining the cost-effectiveness relationships implied by a given abatement policy, for judging the efficacy of competing incentives for abatement, and for indicating productive avenues of research in pollution control.

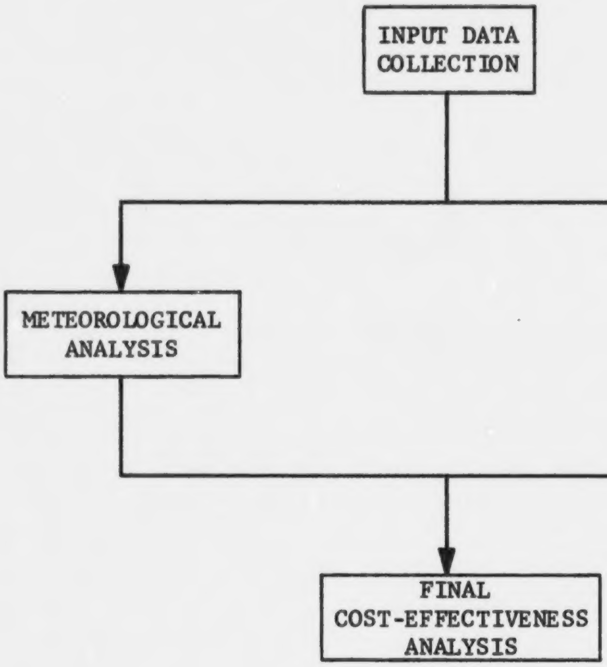
Given the large number of individual emission sources in most urban regions, the scale of any multiple-source abatement analysis is combinatorially so great that computer-assisted simulation is the only analytical method available which can practically meet the above requirements.

ANALYTICAL CONCEPT

A simulation methodology has been developed and applied in five studies for NAPCA. The evolution and application of the methodology is discussed in subsequent chapters. All five studies conformed to the general analytical concept depicted in Exhibit I-1.

EXHIBIT I-1

GENERAL CONCEPT OF ANALYSIS



The input data requirements generally comprise geographic characteristics, meteorological factors, emission source characteristics, fuel use data, and control device data. Meteorological analysis involves the use of mathematical models to transform source emissions into ambient pollutant concentrations at designated receptor points. Abatement analysis concerns selection of the combinations of emission control alternatives which can be feasibly applied to individual emission sources along with the attendant costs for each level of emission reduction. Final cost-effectiveness analysis entails the use of mathematical programming algorithms and other computational aids to evaluate the cost and ambient air quality implied by each abatement strategy and to compare and rank strategies relative to the various measures of effectiveness employed. A more detailed discussion of these analytical phases accompanies the discussion of each of the studies below.

II. MODEL CITY I STUDY

This study (Contract No. PH 27-00103) was undertaken in March 1967 to support the Health Program Analysis Group - Air Pollution appointed by the Assistant Secretary of DHEW for Planning and Evaluation. A complete description of the methods and results of the study are contained in DHEW Program Analysis Report No. 1967-69, "An Economic Analysis of the Control of Sulphur Oxides Air Pollution," December 1967.

OBJECTIVES

This study had two primary objectives:

1. To demonstrate the value of systems analysis and simulation for assessing the costs of various clean air goals and the cost-effectiveness of alternative pollution abatement strategies
2. To provide officials charged with the responsibility for air pollution control with an indication of information needs in pollution abatement analysis. These needs can suggest directions for DHEW research policy

The first objective recognized two points. First, the emission of SO_2 should be controlled with the minimum of public and private expenditure consonant with the level of control desired. Second, because of differences in urban meteorology, distribution and levels of emissions, and the availability of alternative techniques for emission control, the abatement of SO_2 pollution requires analysis by each metropolitan area individually. An analytical procedure encompassing these two points recognizes that there are alternative abatement strategies available to each urban area affected by SO_2 and that different costs are attached to each strategy.

The second major objective of the study had three components. First, it pointed out to those responsible for achieving air pollution abatement the need for the best quantitative techniques available for decision making. Second, the demonstration study served to reveal the complexities inherent in pollution abatement analysis and the scope of the effort required to apply analytical techniques to real urban areas. Third, the demonstration thus pointed out information gaps which will require further research before real applications can begin.

LIMITATIONS

Since this was to be a demonstration study only, the analysis was channeled to prevent the illustration of methodology from being overwhelmed by inessential detail:

3

- The study was limited to abatement of that portion of SO_2 pollution which derives from combustion of fossil fuels; other sources of SO_2 were not considered
- The study focused principally on the economic aspects of pollution abatement

ANALYSIS

Inputs

Exhibit II-1 gives the hypothetical geographical layout of the model city simulated. Exhibit II-2 provides the characteristics of the city required for the subsequent analysis. Exhibit II-3 gives the heat requirements of the city in British thermal units (Btu). SO_2 emissions within the city are assumed to result only from combustion of fossil fuels. Other sources of SO_2 are not considered. Use of coal for space heating of single-family dwellings is considered to be negligible on the East Coast by 1970 and is therefore ignored. Distillate oil and natural gas, which are not usually significant sources of SO_2 pollution are assumed to have no SO_2 emissions. They are included in Exhibit II-3 to reflect a realistic urban fuel-use structure. For simplicity, it is assumed that consumers cannot change from one kind of fuel to another, e.g., from coal to natural gas, or, in the case of an existing fuel mix, change the proportion of Btu's produced by each fuel. Exhibit II-4 gives the SO_2 emissions resulting from the above fuel use. Emissions in grams per second is the input required by the meteorological diffusion model to compute ground level concentrations at designated receptor points.

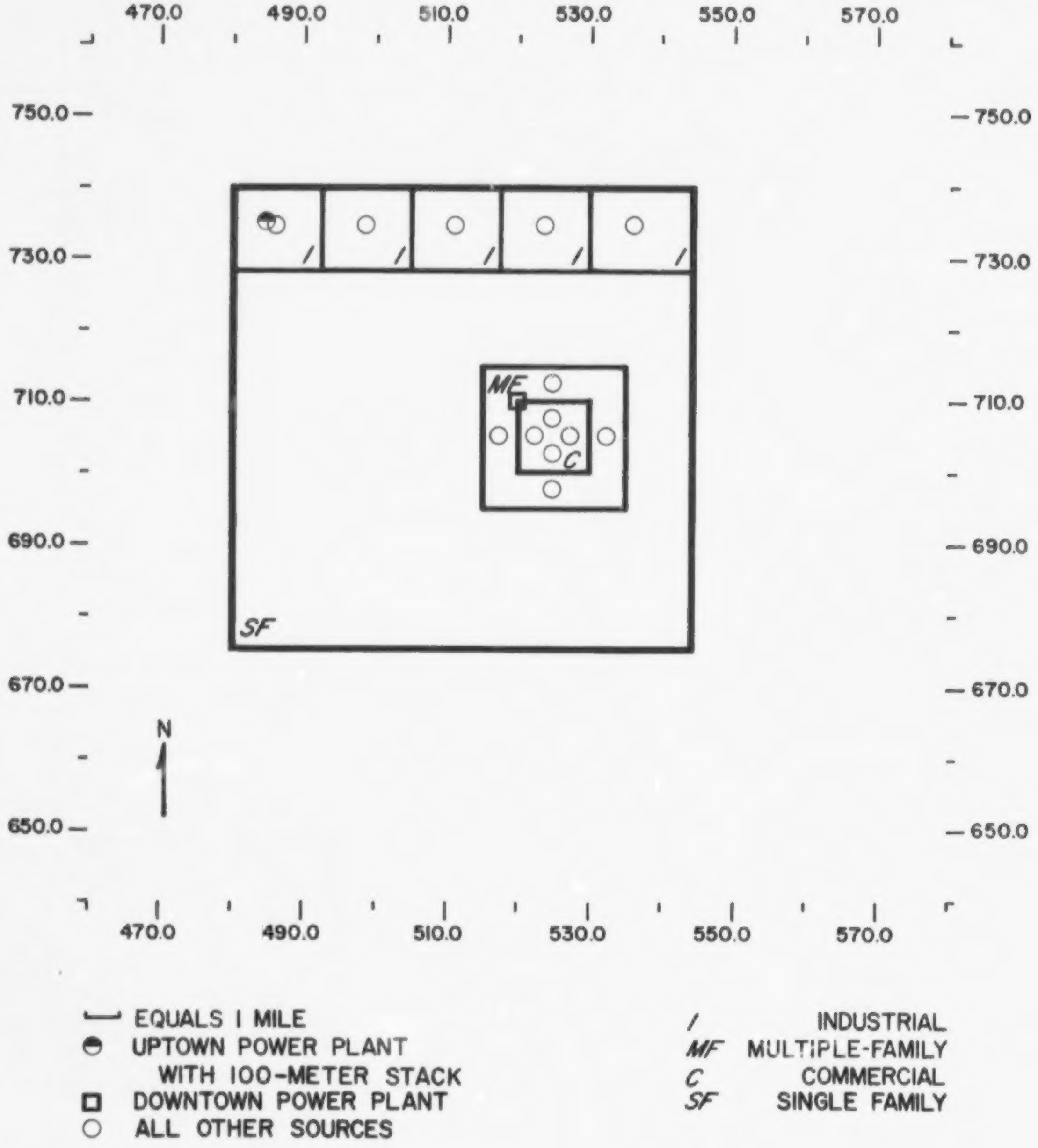
Meteorological Analysis

A computerized meteorological diffusion model, developed by Environmental Science Service Administration was employed to calculate average (mean) annual ground-level pollutant concentration (in parts per million, ppm) at one or more receptor points from a single point source based upon a Gaussian diffusion formula. Required inputs to the computer are (1) grid coordinates of the pollutant source, (2) grid coordinates of the receptor points, (3) effective stack height of the source (1.65 x actual stack height in meters), (4) emission rate of pollutant in gms/sec., and (5) wind speed and direction data appropriate to the studied area. The simplified meteorological model (MET) was programmed in FORTRAN. Wind data from the St. Louis metropolitan area were used with computer concentrations taken as average annual concentrations. Further details of the meteorological model are included in Appendix A, including a FORTRAN listing of the MET program. Exhibit II-5 shows the iso-concentration contours before abatement resulting from the meteorological model analysis. The concentration at any point is the sum of the concentrations contributed to that point by the fifteen point sources. Also, the concentration contributed by an emission source to a point varies directly as the emission rate of the source. The contours in the exhibit were interpolated from concentrations calculated at 44 receptor points throughout the model city.

4

EXHIBIT II-1

GEOGRAPHICAL LAYOUT OF MODEL CITY I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EQUALS I MILE
UPTOWN POWER PLANT WITH 100-METER STACK
DOWNTOWN POWER PLANT
ALL OTHER SOURCES
/ INDUSTRIAL
MF MULTIPLE-FAMILY
C COMMERCIAL
SF SINGLE FAMILY

EXHIBIT II-2

PRINCIPAL CHARACTERISTICS OF MODEL CITY I

Total population	2,000,000
Employment:	
Industrial	440,000
Commercial	360,000
Number of entities/unit:	
Industrial	8,000
Commercial	45,000
Single-family	457,000
Multiple-family	160,000
Number of people per	
Single-family unit	3.5
Multiple-family unit	2.5
Number of employees per	
Industrial entity	55
Commercial entity	8
Number of units/entities per square mile:*	
Single-family	3,800
Multiple-family	13,000
Industrial	276
Commercial	11,250
Size:	
Single-family area	119 square miles
Multiple-family area	12 square miles
Industrial area	30 square miles
Commercial area	4 square miles
Power plants: Uptown plant in northwest area operates 24 hours a day at heat rate of 9,000 Btu/kwh. Downtown plant in commercial area operates during daylight hours at heat rate of 15,000 Btu/kwh.	
Stack heights:	
Power plants	
Uptown	100 meters 200 meters for high stack
Downtown	50 meters
Industrial (all same)	30 meters
Commercial (all same)	40 meters
Multiple-family (all same)	15 meters
Exposure densities (average number of people per square mile per day):**	
Single-family	11,600
Multiple-family	24,300
Commercial	44,600
Industrial	4,900

---

* Square mile = 25 million square feet in this study.

** Average length of work day is assumed to be eight hours. In addition, daily migration from the single- and multiple-family sectors to the commercial sector has been assumed to involve 350,000 people with an average stay of four hours.

EXHIBIT II-3

HEAT REQUIREMENTS OF MODEL CITY[a]

Fuel User Class	Heat Requirement in Btu X 10^{12}			
	Coal	Oil	Distillate Oil & Natural Gas	Total
Power plants	90.6[b]	49.4[d]	0	140.0
Industrial	21.0[b]	29.0[d]	73.0	123.0
Commercial	3.0[c]	12.0[d]	12.0	27.0
Multiple-family	1.0[c]	0	16.0	17.0
Single-family	0	0	56.0	56.0
TOTAL	115.6	90.4	157.0	363.0

a/ Data represent projected national fuel use structure for 1970, abstracted from Resources in Amercia's Future, (Resources for the Future, Inc., Johns Hopkins Press, 1963).

b/ 2.5 percent sulfur coal with a Btu rating of 24 million Btu/ton is assumed.

c/ 3.0 percent sulfur coal with a Btu rating of 24 million Bti/ton is assumed.

d/ 2.5 percent residual oil with a Btu rating of 6.3 million Btu/barrel is assumed.

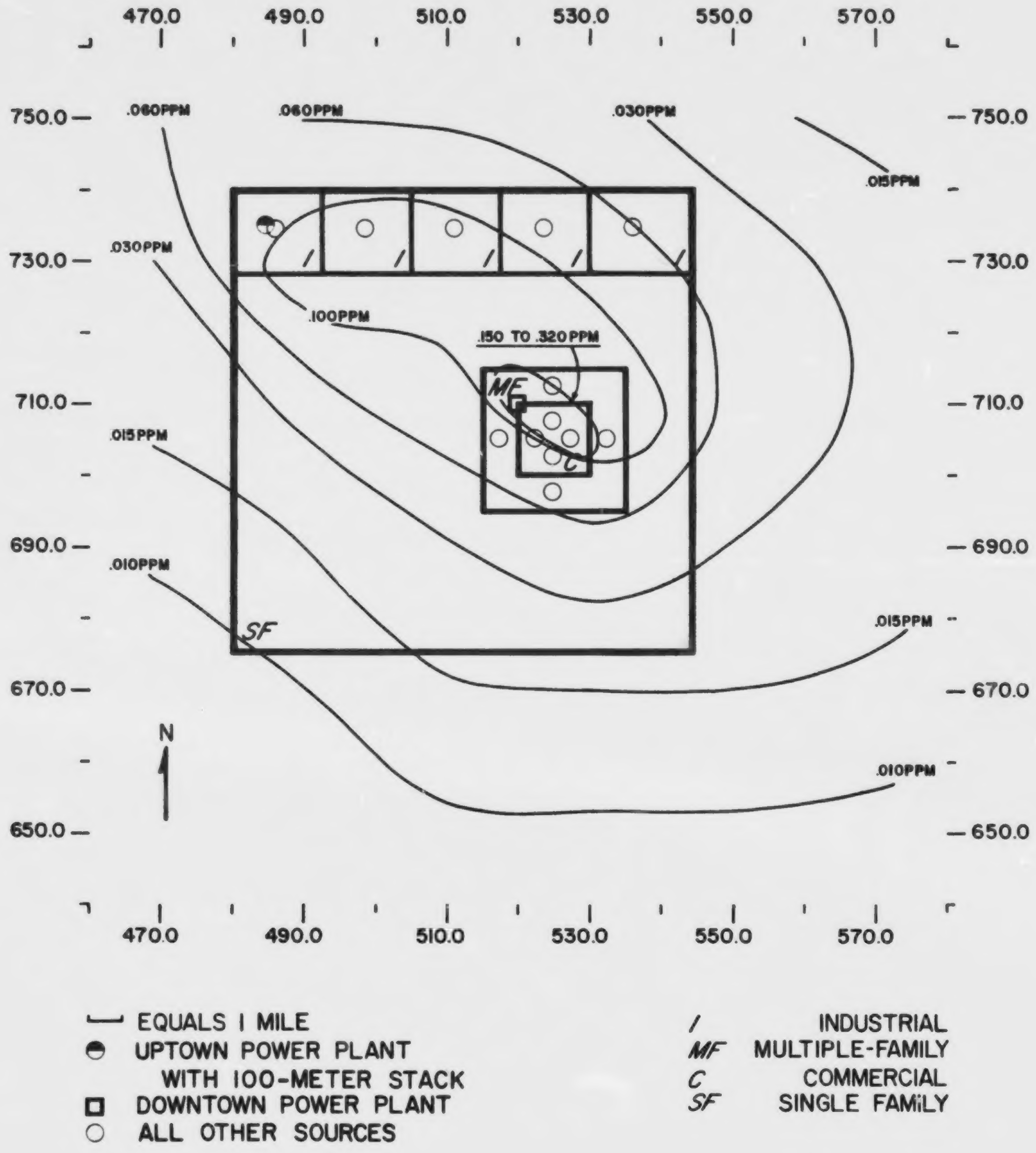
EXHIBIT II-4

SO_2 EMISSION INVENTORY

Source	Fuel Used (tons per year)			SO_2 Emissions
	Coal	Residual Oil	Total	
Power plants:				
Uptown	97,700	64,700	162,400	4,660
Downtown	81,500	-0-	81,500	2,340
	179,200	65,700	243,900	7,000
Other sources:				
Industrial	41,500	38,000	79,500	2,280
Commercial	7,100	15,700	22,800	655
Multiple family	2,400	-0-	2,400	70
	51,000	53,700	104,700	3,005
TOTAL	230,200	118,400	348,600	10,005

EXHIBIT II-5

AVERAGE ANNUAL SULFUR DIOXIDE CONCENTRATIONS (PPM): ALL SOURCES, BEFORE ABATEMENT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EQUALS 1 MILE
UPTOWN POWER PLANT WITH 100-METER STACK
DOWNTOWN POWER PLANT
ALL OTHER SOURCES
/ INDUSTRIAL
MF MULTIPLE-FAMILY
C COMMERCIAL
SF SINGLE FAMILY

8

Abatement Analysis

Most of the currently available techniques for controlling SO_2 from combustion sources were considered in this study. However, it was not possible to allow all options within each emitting sector. The control options allowed are discussed below.

(1) Fuel Substitution - In this analysis, only fuel substitution was allowed; for any purpose, fuel switching was not used. It was further assumed that users would be forced by nonpollution considerations to retain the original fuel mix between coal, oil, and gas.

(2) Fuel Desulfurization - It was assumed that the practical lower limit for residual oil desulfurization is 0.5 percent. A 50 percent limit on pyritic sulfur removal was used for coal desulfurization.

(3) Stack Gas Cleaning - At the time of this study (1967), SO_2 stack gas cleaning processes then in the pilot stage were included as control options for power plants only.

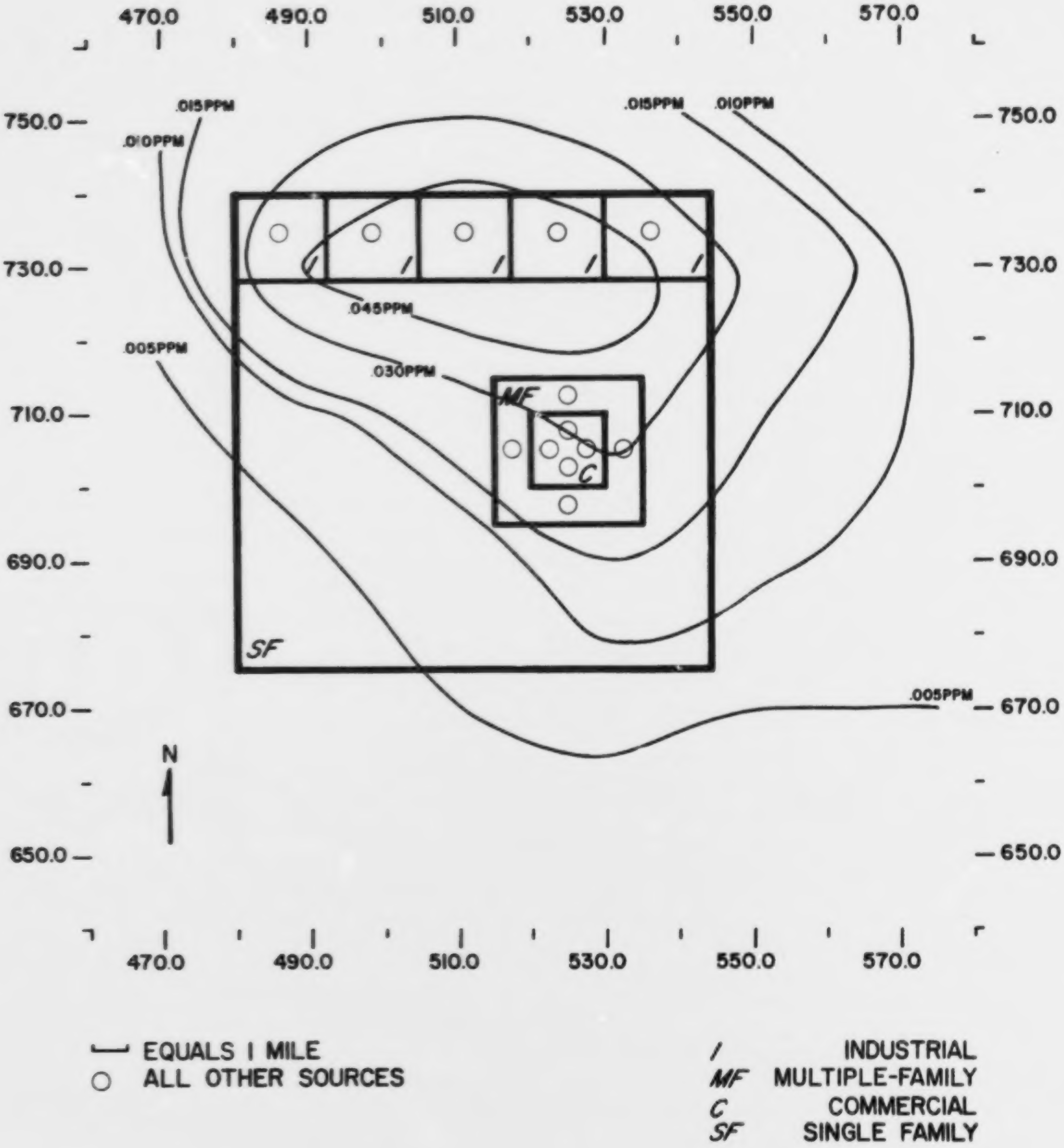
(4) Increased Stack Height - It was assumed that the stack height for the large power plant in the northwest corner of the city (see Exhibit II-1) could be increased only to 200 meters and that the stack height for the other power plant could not be changed. All emissions other than those from the power plants were assumed to be at elevations at or below 40 meters, as detailed previously in Exhibit II-2.

(5) Zoning and Relocation - Since this analysis was of the current situation in the model city, zoning of future emission sources was not an appropriate technique for control. Though the relocation of both power plants outside the urban area was not considered in the cost analysis because of the much greater uncertainties in estimating the costs involved, the concentrations resulting from relocation are shown in Exhibit II-6.and may be compared to the concentrations shown in Exhibit II-5. Since no other significant single sources were specified for the model, other relocations were not considered.

The availability of each of the above techniques for SO_2 control is summarized in Exhibit II-7. Techniques 1 and 2, fuel substitution and fuel desulfurization, are combined in the exhibit under "fuel change."

EXHIBIT II-6

AVERAGE ANNUAL SULFUR DIOXIDE CONCENTRATIONS (PPM): ALL SOURCES, POWER PLANTS OUT OF TOWN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EQUALS I MILE
ALL OTHER SOURCES
/ INDUSTRIAL
MF MULTIPLE-FAMILY
C COMMERCIAL
SF SINGLE FAMILY

EXHIBIT II-7

AVAILABILITY OF TECHNIQUES FOR SO_2 CONTROL

Source	Fuel Change[a/]		Stack Gas Cleaning	Increased Stack Height
	Coal	Residual Oil		
Power plants:				
Uptown	A	A	A	A
Downtown	A	NA	A	NA
Other sources:				
Industrial	A	A	NA	NA
Commercial	A	A	NA	NA
Multiple-family	A	NA	NA	NA

a/ Low sulfur fuel, including desulfurized fuel, for high sulfur fuel of the same type.

NA = Not available

A = Available

The costs of the individual control techniques for different levels of emission reduction are given in the full study report.[46/] The cost details are too voluminous to be included in this summary.

Final Analysis

Two general strategies were simulated in this study, the Equiproportional (EP) strategy and the Least Cost (LC) strategy.

(1) Equiproportional Strategy - This strategy is the minimum cost combination of SO_2 emission controls which achieves exactly the same percentage emission reduction at each of the 15 point sources. It does not require uniform reduction in emissions from each of the fuels used at a source. For example, a 20 percent reduction in emissions from a point where the emissions are divided evenly between coal and residual oil may be accomplished by a 30 percent reduction in emissions from coal and a 10 percent reduction in emissions from oil. The EP strategy allows a choice among the several techniques for SO_2 control available to each emitting sector (see Exhibit II-7). Several combinations of emission control techniques for

11

achieving equiproportional control were applied to obtain costs of the strategy under four different measures of effectiveness, including the lowest cost combination. Since the lowest cost combination under the EP strategy is constrained by the requirement to reduce all emissions at each source by the same percentage, its cost is generally higher than that of the LC strategy, which is not so constrained.

(2) Least cost strategy - The LC strategy is the minimum cost combination of SO_2 emission controls which achieves no more and no less than the stipulated abatement effectiveness. The minimum cost can be calculated in a particular situation by first determining the cost per gram/second (or ppm, or unit measure of exposure) reduced for each SO_2 control technique available to each emitting sector at each level of control. Second, the technique with the lowest unit cost is applied until its unit cost equals the next highest unit cost of another control technique. At this point, both are applied until the unit cost of one exceeds the other or until both unit costs exceed that of a third technique, and so on until the level of control is either achieved or approached as close as possible.

The computational procedure in applying the strategies becomes successively more complex as the strategies are applied to the four measures of abatement effectiveness selected. The measures of effectiveness are (1) reduction in total urban emissions of SO_2, (2) reduction in the highest SO_2 concentration, (3) reduction of all concentrations to 0.050 or less, and (4) reduction in total human exposure.

COST-EFFECTIVENESS RESULTS

The EP and LC strategies were applied to achieve the levels of abatement stipulated for each measure of effectiveness employed:

(1) Reduce total urban emissions by 20, 40, 60, 80, and maximum percent

- Equiproportional strategy: Exhibit II-8 shows for each source the average annual emissions (grams per second) before control, average annual emissions at 20, 40, 60, 80, and maximum percent, the technique of achieving control, and the estimated annual costs.
- Least cost strategy: Exhibit II-9 shows information similar to Exhibit II-8 for the LC strategy.

12

EXHIBIT II-8

COST OF REDUCING EMISSIONS BY EQUIPROPORTIONAL STRATEGY

	Average Annual Emissions gms/sec Before Reduction	20% Reduction			40% Reduction			60% Reduction			80% Reduction[a]			Maximum Reduction (89%)		
		Annual Emissions gm/sec	Method	Estimated Annual Cost (000)	Average Annual Emissions gm/sec	Method	Estimated Annual Cost (000)	Average Annual Emissions gm/sec	Method	Estimated Annual Cost (000)	Average Annual Emissions gm/sec	Method	Estimated Annual Cost (000)	Average Annual Emissions gm/sec	Method	Estimated Annual Cost (000)
Power plants:																
Uptown	4,660	3,730	Fuel sub.	$1,641	2,795[b]	High stack	$ 230	1,865[b]	High stack with fuel sub.	$ 3,184	745[b]	High stack with stack clean.	$ 6,280	90[b]	High stack, stack clean. and fuel sub.	$17,157
Downtown	2,340	1,870	" "	824	1,405	Fuel sub.	1,648	935	Stack clean.	4,000	375	Stack clean	4,920	95	Stack clean.	9,220
	7,000	5,600		2,465	4,200		1,878	2,800		7,184	1,120		11,200	185		26,377
Other sources:																
Industrial	2,280	1,820	Fuel sub.	813	1,365	Fuel sub.	2,145	915	Fuel sub.	4,275	695	Fuel sub.	5,145	695	Fuel sub.	5,145
Commercial	655	525	" "	240	395	" "	684	260	" "	1,188	160	" "	1,620	160	" "	1,620
Multi-family	70	55	" "	24	40	" "	48	30	" "	96	25	" "	120	25	" "	120
	3,005	2,400		1,077	1,800		2,877	1,205		5,559	880		6,885	880		6,885
TOTAL	10,005	8,000		$3,542	6,000		$4,755	4,005		$12,743	2,000		$18,085	1,065		$33,262

[a] 80% control cannot be achieved by sources other than the power plants.

[b] Effective, not absolute, reduction due to increased mixing height of effluents.

14

EXHIBIT II-9

COST OF REDUCING EMISSIONS BY
LEAST COST STRATEGY

Source	Average Annual Emissions gms/sec Before Reduction	20% Reduction			40% Reduction			60% Reduction			80% Reduction			Maximum Reduction (89%)		
		Average Annual Emissions gms/sec	Method	Estimated Annual Cost (000)	Average Annual Emissions gms/sec	Method	Estimated Annual Cost (000)	Average Annual Emissions gms/sec	Method	Estimated Annual Cost (000)	Average Annual Emissions gms/sec	Method	Estimated Annual Cost (000)	Average Annual Emissions gms/sec	Method	Estimated Annual Cost (000)
Power plants:																
Uptown (100 meter stack)	4,660	2,655a/	High stack and fuel sub.	$477	2,490a/	High stack and fuel sub.	$1,223	280a/	High stack and stack cleaning	$7,030	280a/	High stack and stack cleaning	$ 7,030	90a/	High stack stack cleaning and fuel sub.	$17,157
Downtown	2,340	2,340	NC		1,405	Fuel sub.	1,648	1,615	Fuel sub.	1,278	235	Stack cleaning	5,100	95		9,220
	7,000	4,995		477	3,895		2,871	1,895		8,308	515		12,130	185		26,377
Other sources:																
Industrial	2,280	2,280	NC		1,585	Fuel sub.	1,275	1,585	Fuel sub.	1,275	1,120	Fuel sub.	3,426	695	Fuel sub.	5,145
Commercial	655	655	NC		485	" "	324	485	" "	324	340	" "	900	160	" "	1,620
Multiple family	70	70	NC		35	" "	60	35	" "	60	25	" "	120	25	" "	120
	3,005	3,005			2,105		1,659	2,105		1,659	1,485		4,446	880		6,885
TOTAL	10,005	8,000		$477	6,000		$4,530	4,000		$9,967	2,000		$16,576	1,065		$33,262

NC = No control

a/ Effective, not absolute, reduction due to increased mixing height of effluents.

- Difference in cost and relative efficiency of the EP and LC strategies: The largest difference in cost between the two strategies is \$3,065,000, which occurs at 20 percent reduction where the EP strategy costs \$3,542,000 and the LC \$477,000. Note that in Exhibit II-8 the cost of reduction of 40 percent in the SO_2 emissions of the Uptown power plant is substantially less than the cost for a 20 percent reduction. This peculiarity arose both from the - perhaps too restrictive - requirement that emissions must be reduced to no more and no less than the stipulated percentage and from the relatively low annualized cost assumed for the high stack. If the efficiency of the EP is defined as the ratio of the cost of the LC strategy to the cost of the EP strategy multiplied by 100, EP strategy efficiencies are 14, 98, 79, and 92 percent for emission reductions of 20, 40, 60, and 80 percent respectively. (See EP strategy costs in Exhibit II-8 and LC costs in Exhibit II-9.) Maximum reduction necessarily costs the same for any strategy.

(2) Reduce highest concentration by 20, 40, 60, 80, and maximum percent

The point of highest concentration (0.316 ppm) in Exhibit II-5 occurs at grid coordinates H-517.5 and V-712.5.

- Equiproportional strategy: Exhibit II-10 gives the costs of reducing the highest concentration by 20, 40, 60, 80, and maximum (93) percent. The costs are the same as those in Exhibit II-8 since the EP strategy is applied to emission sources, not receptor points.

EXHIBIT II-10

COST AND REDUCTION OF HIGHEST CONCENTRATION BY EQUIPROPORTIONAL STRATEGY

Percent Reduction	Average Annual Concentrations (ppm)	Estimated Annual Cost[a/] (000)
0	0.316	---
20	0.253	\$ 3,542
40	0.190	4,755
60	0.126	12,743
80	0.063	18,085
93	0.021	33,262

[a/] From Exhibit II-8. The same techniques of reduction apply.

15

- Least Cost strategy: Exhibit II-11 gives the least cost results for the same concentration reductions.

- Difference in cost and relative efficiency of the EP and LC strategies: The largest difference in cost, $9,871,000, occurs at 80 percent reduction. The efficiency of the EP strategy is 29, 57, 35, and 45 percent at 20, 40, 60, and 80 percent reduction respectively.

(3) Reduce all concentrations to 0.050 ppm or less

- Equiproportional strategy: Exhibit II-12 lists all receptor points with average annual concentrations innexcess of 0.050 ppm and shows the percentage reduction in the concentrations necessary to reach 0.050 ppm. Exhibit II-13 shows the percent contribution of all sources to each one of the points listed on Exhibit II-12. From the percengage contributions of each source, it is possible to conclude that an EP strategy for reduction in all concentrations to 0.050 ppm is not feasible. First, not all sources can attain 80 to 90 percent reduction in emissions. Second, the proportionate contributions of the sources to the concentration at a receptor point vary widely. This implies there is no single reduction, short of 80 to 90 percent, which can be applied uniformly to all sources to bring all receptor point concentrations to 0.050 ppm or less.

- Least Cost strategy: Exhibit II-14 shows the estimated annual cost to all sources and the total cost of reducing all concentrations within the model city to 0.050 ppm or less. The table also shows the techniques for achieving reduction and the percentage reduction in emissions from each source (the amount by which all concentrations due to that source are to be reduced). Exhibit II-15 shows the concentrations at the receptor coordinate locations after reductions have been applied.

EXHIBIT II-11

COST OF REDUCING HIGHEST CONCENTRATION BY LEAST COST STRATEGY

Source	Average Annual Concentration Before Reduction ppm	%	20% Reduction Concentration ppm	%	Method	Estimated Annual Cost (000(	40% Reduction Concentration ppm	%	Method	Estimated Annual Cost (000)	60% Reduction Concentration ppm	%	Method	Estimated Annual Cost (000)	80% Reduction Concentration ppm	%	Method	Estimated Annual Cost (000)	Maximum Reduction (93%) Concentration ppm	%	Method	Estimated Annual Cost (000)
Power plants:																						
Uptown (100 meter stack)	0.018	5.4	0.018	7.1	NC		0.018	9.5			0.018	14.3	NC		0.011[a]	17.5	High stack	$ 230	0.0005[a]	2.4	Maximum fuel sub. stack cleaning and high	$17,157
Downtown	0.262	83.3	0.199	78.5	Fuel sub.	$989	0.136	71.6	Fuel sub.	$2,643	0.072	57.1	Stack Cleaning	$4,520	0.016	25.4	Fuel sub. and stack cleaning	7,984	0.0105	50.0	Maximum fuel sub. and stack cleaning	9, 220
	0.280	88.7	0.217	85.6			0.154	81.1			0.090	71.4			0.027	42.9		8,214	0.0110	52.4		26,377
Other sources:																						
Industrial	0.012	3.6	0.012	4.7	NC		0.012	6.3	NC		0.012	9.5	NC		0.012	19.0	NC		0.0040	19.0	Maximum fuel sub.	5,145
Commercial	0.021	6.6	0.021	8.3	NC		0.021	11.0	NC		0.021	16.7	NC		0.021	33.3	NC		0.0050	23.8	" "	1,620
Multi-family	0.003	1.1	0.003	1.2	NC		0.003	1.6	NC		0.003	2.4	NC		0.003	4.8	NC		0.0010	4.8	" "	120
	0.036	11.3	0.036	14.2			0.036	18.9			0.036	28.6			0.036	57.1			0.0100	47.6		6,885
TOTAL	0.036	100.0	0.253	100.0		$989	0.190	100.0		$2,643	0.126	100.0		$4,520	0.063	100.0		$8,214	0.0210	100.0		$33,262

NC = No control

[a] Effective, not absolute, reduction due to increased mixing height of effluents.

EXHIBIT II-12

PERCENT REDUCTIONS NECESSARY TO REDUCE ALL CONCENTRATIONS TO 0.050 PPM OR LESS

Coordinates		Total SO_2 Concentration Before Reduction (ppm)	Percent Reduction To Achieve 0.050 ppm
Horiz.	Vert.		
517.5	712.5	0.316	84.2
722.5	707.5	0.275	81.8
527.5	707.5	0.262	80.9
527.5	702.5	0.176	71.5
530.0	710.0	0.156	67.9
722.5	702.5	0.135	63.0
490.0	730.0	0.131	61.
510.0	730.0	0.129	61.2
532.5	712.5	0.092	45.6
530.0	730.0	0.082	39.0
510.0	710.0	0.080	37.5
532.5	697.5	0.074	32.4
470.0	750.0	0.063	20.6
490.0	750.0	0.060	16.7
517.5	697.5	0.055	9.1
510.0	750.0	0.055	9.1

EXHIBIT II-13

PERCENT CONTRIBUTIONS OF ALL SOURCES TO CONCENTRATIONS IN EXCESS OF 0.050 PPM

Coordinates		Power Plants			Other Sources			
		Up-town	Down-town	Total	Ind.	Comm.	Multiple-family	Total
Horiz.	Vert.							
517.5	712.5	5.6%	83.0%	88.6%	3.8%	6.6%	1.0%	11.4%
722.5	707.5	5.1	62.5	67.6	3.6	27.8	1.0	32.4
527.5	707.5	5.0	55.0	60.0	3.4	34.7	1.9	40.0
527.5	702.5	6.3	41.5	47.8	4.0	46.5	1.7	52.2
530.0	710.0	9.6	66.6	76.2	7.1	12.8	3.9	23.8
722.5	702.5	8.9	51.8	60.7	5.9	28.9	4.5	39.3
490.0	730.0	57.2	7.7	64.9	33.6	1.5	-0-	35.1
510.0	730.0	30.2	20.9	51.1	45.0	3.9	-0-	48.9
532.5	712.5	17.4	53.2	70.6	14.1	10.9	4.4	29.4
530.0	730.0	22.0	13.4	35.4	56.1	7.3	1.2	64.6
510.0	710.0	25.0	50.0	75.0	12.5	11.3	1.2	25.0
532.5	697.5	12.2	47.3	59.5	8.1	28.4	4.0	40.5
470.0	750.0	73.0	8.0	81.0	17.5	1.5	-0-	19.0
490.0	750.0	50.0	11.7	61.7	35.0	3.3	-0-	38.3
517.5	697.5	20.0	56.4	76.4	10.9	9.1	3.6	23.6
510.0	750.0	25.5	20.0	45.5	49.1	5.4	-0-	54.5

18

EXHIBIT II-14

COST OF REDUCING CONCENTRATIONS TO 0.050 PPM OR LESS BY LEAST COST STRATEGY

Source	Technique for Reduction	Estimated Annual Cost (000)	Emissions (gms/sec)		
			Before Reduction	After Reduction	Reduction
Power plants:					
Uptown	High stack and fuel sub.	$ 2,038	4,660	2,180	53.2%
Downtown	Stack gas cleaning	5,100	2,340	235	90.0
		7,138	7,000	2,415	65.5
Other sources:					
Industrial	Maximum fuel sub.	5,145	2,280	695	69.5
Commercial	Maximum fuel sub.	1,620	655	160	75.6
Multiple-family	Maximum fuel sub.	120	70	25	64.2
		6,885	3,005	880	70.7
		$15,023	10,005	3,295	67.1%

(4) Reduce human exposure by 20, 40, 60, 80, and maximum percent

An appropriate measure of human exposure to SO_2 in the model city is first required. To develop a possible measure, consider a small subarea of the city over which the average annual SO_2 concentration is approximately constant. From the densities given in Exhibit II-2, the population of the subarea can be calculated, and exposure may be defined in the subarea as the product of this population times the average annual concentration. If the model city is divided into n such subareas, the total human exposure, E, in the city is simply the sum of the n subarea exposures. That is,

$$E = C_1 P_1 + C_2 P_2 + \ldots + C_n P_n$$

where any C_i denotes the average annual SO_2 concentration in the i-th subarea and P_i denotes the total population in the i-th subarea. E will be called "unweighted exposure" (for reasons explained below), and it is measured in units of people times ppm, hereafter abbreviated p-ppm. In physical reality, of course, concentrations vary continuously over the surface of the city (i.e., concentration is not really constant over any subarea, however small). Thus E is a discrete approximation to the number of "p-ppm" under the continuous contour of concentrations covering the city. This approximation can be made as accurate as desired by dividing the city into a sufficiently large number of subareas (i.e., making the subareas sufficiently small).

- Equiproportional strategy: For actual computation, the model city was divided into 23 subareas, each of which is roughly centered about a receptor point. The first column of Exhibit II-15 shows the total "unweighted" human exposure in the model city before abatement and the contribution of each source contributing to that total. The exhibit also shows the costs associated with reducing this total unweighted exposure by 20, 40, 60, 80, and 83 percent with an EP emission reduction strategy. Again, the costs are necessarily the same as in Exhibit II-8 for the corresponding emission reductions.

- Least cost strategy: Least cost strategies were developed for effecting the same reductions in unweighted human exposure as were effected by the simulated EP strategy. Exhibit II-16 shows

20

EXHIBIT II-15

COST OF REDUCING UNWEIGHTED EXPOSURE BY EQUIPROPORTIONAL STRATEGY

Source	Average Annual Exposure Before Reduction (p-ppm)	%	20% Reduction			40% Reduction			60% Reduction			80% Reduction			Maximum Reduction (83%)		
			Average Annual Exposure (p-ppm)	Method	Esti-mated Annual Cost (000)	Average Annual Exposure (p-ppm)	Method	Esti-mated Annual Cost (000)	Average Annual Exposure (p-ppm)	Method	Esti-mated Annual Cost (000)	Average Annual Exposure (p-ppm)	Method	Esti-mated Annual Cost (000)	Average Annual Exposure (p-ppm)	Method	Esti-mated Annual Cost (000)
Power Plants:																	
Uptown	36,104	21.5	28,880	Fuel sub.	$1,641	21,660	High stack	$ 230	14,440	High stack, fuel sub.	$ 3,184	7,220	High stack, stack clean.	$ 6,280	412	High stack, stack clean, & fuel sub.	$17,157
Downtown	69,279	41.3	55,400	Fuel sub.	824	41,500	Fuel sub.	1,648	27,640	Stack clean.	4,000	13,820	Stack clean.	4,920	2,760	Stack clean	9,220
	105,383	62.8	84,280		2,465	63,160		1,878	42,080		7,184	21,040		11,200	3,172		26,377
Other Sources:																	
Industrial	29,547	17.6	23,600	Fuel sub.	813	17,700	Fuel sub.	2,145	11,800	Fuel sub.	3,275	5,900	Fuel sub.	5,145	11,800	Fuel sub.	5,145
Commercial	30,404	18.0	24,400	" "	240	18,300	" "	684	12,200	" "	1,188	6,100	" "	1,620	12,304	" "	1,620
Multiple family	2,750	1.6	2,200	" "	24	1,650	" "	48	1,100	" "	96	550	" "	120	900	" "	120
	62,701	37.2	50,200		1,077	37,650		2,877	25,100		4,559	12,550		6,885	25,004		6,885
TOTAL	168,084	100	134,480		$3,542	100,810		$4,755	67,180		$11,743	33,590		$18,085	28,176		$33,262

EXHIBIT II-16

COST OF REDUCING UNWEIGHTED EXPOSURE BY LEAST COST STRATEGY

Source	Average Annual Exposure Before Reduction		20% Reduction			40% Reduction			60% Reduction			80% Reduction			Maximum Reduction (83%)		
	(p-ppm)	%	Average Annual Exposure (p-ppm)	Method	Estimated Annual Cost (000)	Average Annual Exposure (p-ppm)	Method	Estimated Annual Cost (000)	Average Annual Exposure (p-ppm)	Method	Estimated Annual Cost (000)	Average Annual Exposure (p-ppm)	Method	Estimated Annual Cost (000)	Average Annual Exposure (p-ppm)	Method	Estimated Annual Cost (000)
Power plants:																	
Uptown	36,104	21.5	21,700	High stack	$ 230	21,700	High stack	$ 230	21,700	High stack	$ 230	2,200	High stack, stack clean.	$ 7,020	412	High stack, stack clean., and fuel sub.	$17,157
Downtown	69,279	41.3	69,279	NC		36,579	Fuel sub.	3,040	6,928	Stack clean.	5,130	6,928	Stack clean.	5,130	2,760	Stack clean.	9,220
	105,383	62.8	90,979		230	58,279		3,270	28,628		5,360	9,128		12,150	3,172		26,377
Other sources:																	
Industrial	29,547	17.6	29,547	NC		29,579	NC		28,400	Fuel sub.	157	11,800	Fuel sub.	4,280	11,800	Fuel sub.	5,145
Commercial	30,404	18.0	12,304	Fuel sub.	1,170	12,304	Fuel sub.	1,170	12,304	" "	1,170	12,304	" "	1,170	12,304	" "	1,620
Multiple family	2,750	1.6	1,740	" "	41	900	" "	126	900	" "	126	900	" "	126	900	" "	120
	62,701	37.2	43,591		1,211	42,783		1,296	41,604		1,453	25,004		5,576	25,004		6,885
TOTAL	168,084	100	134,570		$1,441	101,062		$4,566	70,232		$6,813	34,132		$17,726	28,176		$33,262

the control techniques used to attain each level of reduction, the costs associated with each level of reduction, and the exposure contributions of the various emitting sources at each level of reduction.

- Differences in costs and relative efficiency of the EP and LC strategies: The largest difference in cost between the two strategies is $5,930,000, which occurs at 60 percent reduction, where the EP strategy costs $12,743,000 and the LC strategy $6,813,000. The two strategies give identical costs only for the maximum attainable reduction, for which all available abatement technologies are employed. The two strategies yield similar costs for 40 and 80 percent reductions, but the least cost strategy is much less expensive for the 20 percent ($1,441,000) and the 60 percent ($6,813,000) reductions. The efficiency of the EP strategy in reducing unweighted human exposure is 40, 96, 54, and 98 percent at the 20, 40, 60, and 80 percent reduction levels respectively.

- Nonlinear human exposure: It should be emphasized that the measure of human exposure developed above is only one of many possible definitions. In this measure, all people are treated equally. Under this criterion, each subarea of the city is distinguished by the number of people exposed in the area and the concentrations to which they are exposed. For the purposes of demonstration again, consider a small subarea of the model city over which the average annual SO_2 concentration is essentially constant and has a value C = 0.050 ppm. Suppose that the population of the subarea is 1,000 and that a system of weights has been worked out which reflects the fact that up to a point higher levels of pollution are more harmful than lower levels and on that basis assigns a weight of 16 to the concentration of 0.050 ppm. That is, one person exposed to a concentration of 0.050 ppm is deemed to be 16 units more important than one person exposed to some base-level or benchmark concentration. The nonlinear human exposure in the subarea may be defined then as the product of the weight assigned to the average annual concentration and the population of the subarea.

  Two possible (and purely hypothetical) weighting functions are presented in Exhibit II-17. Both functions place a weight of zero on concentrations below the air quality criterion, 0.015 ppm, and both functions increase nonlinearly (but in discrete steps) for concentrations between 0.015 and 0.250 ppm. In examining both functions the important point is the decrement of weight which results from the decrease in pollution. For example, in function #1, reducing the concentration from 0.225 to 0.240 results in a decrement of weight of 50 (460-410). Function #1 increases in fairly regular increments for concentrations above 0.240, where function #2 places a very high weight on concentrations above 0.240. Function #2 might provide an appropriate measure of effective exposure if 0.240 ppm were judged to be the lowest SO_2 concentration at which abatement is obligatory. (The particular value of 0.240 ppm has been chosen for demonstration purposes only and is not to be taken as a recommendation.)

EXHIBIT II-17

HYPOTHETICAL WEIGHTING FUNCTIONS

Annual Average Concentration C	Weights of Concentration Function #1 $W(C)_1$	Increment $\Delta W(C)_1$	Weights of Concentration Function #2 $W(C)_2$	Increment $\Delta W(C)_2$
0-0.014	0		0	
0.015-0.029	2	2	2	2
0.030-0.044	7	5	7	5
0.045-0.059	16	9	16	9
0.060-0.074	27	11	27	11
0.075-0.089	40	13	40	13
0.090-0.104	60	20	60	20
0.105-0.119	80	20	80	20
0.120-0.134	100	20	100	20
0.135-0.149	130	30	130	30
0.150-0.164	160	30	160	30
0.165-0.179	190	30	190	30
0.180-0.194	230	40	230	40
0.195-0.209	270	40	270	40
0.210-0.224	310	40	310	40
0.225-0.239	360	50	360	50
0.240-0.254	410	50	2800	2440
0.255-0.269	460	50	2970	170
0.270-0.284	510	50	3150	180
0.285-0.299	570	60	3340	190
etc.				

The abatement problem is to allocate the expenditure of funds so that the greatest decrement in weighted exposure is achieved for a given level of expenditure. Alternatively if it is decided to reduce human exposure by a certain amount, then the decrement "purchased" with each successive dollar should be as large as possible until the desired level is reached.

For example, using function #2, there are three subareas of the model city with initial concentrations (i.e., before abatement) above 0.240 ppm. That is, there are three subareas initially in the "penalty category" with a weight of at least 2800. A very inexpensive control procedure may bring these concentrations below 0.240 ppm and hence effect a reduction in weighted human exposure. Exhibit II-18 also shows that widely different results can be obtained using the two different weighting functions.

For example, with function #1, $1,648,000 purchases a decrement of weighted human exposure roughly one-third of the amount purchased when function #2 is used as the weight.

EXHIBIT II-18

Annual Average Concentration C	Function #1		Function #2	
	$W(C)_1$	Decrement of Exposure Gained per Capita	$W(C)_2$	Decrement of Exposure Gained per Capita
0.299-0.285	570		3340	
0.284-0.270	510	60	3150	190
0.269-0.255	460	50	2970	180
0.254-0.240	410	50	2800	170
Total		160		540

Broader implications of weighting functions: The pollution control objectives posed in this study represent an increasing order of sophistication. Ultimately, concern does not rest upon emissions, nor upon the concentrations caused by emissions, nor upon the exposures caused by concentrations. Rather, the final quantity of concern is the damage or discomfort resulting from such exposures. Thus, any attempt to weight exposures appropriately is in actuality an attempt to develop an "effective exposure" or "damage function." If such a function is well constructed, and if it shows that a very small reduction in emissions can yield a very large reduction in "damage," then the appropriate conclusion is that very powerful abatement procedures are available.

III. MODEL CITY II STUDY

This study, undertaken in July 1967, was funded by NAPCA under Contract No. PH27-68-23 for the President's Council of Economic Advisers. The Council wished to assess the impact of various financial incentives on the cost and effectiveness of urban air pollution abatement. No final comprehensive report of this study was requested. The results were communicated informally to the Council in October 1967 for internal use only at that time. The results are now public information.

OBJECTIVES

The following objectives were stipulated for this study:

- To expand the Model City I simulation (see Chapter II) to encompass more realistic detail, including a number of different kinds of industrial pollution sources and both sulfur oxides and particulate emissions

- To automate the simulation to the extent feasible to minimize professional and clerical effort

- To apply the improved simulator to analyze the economic impact of several financial incentive schemes under alternative abatement strategies

- To meet the first objective, 47 emission sources of sulfur oxides (SO_x) and/or suspended particulate (SP) were hypothesized for the model city.

Of these 47 sources, 27 are point sources, and 20 are area sources. Point sources emit more than 100 tons a year of a single pollutant; area sources emit less than 100 tons a year and are aggregated on an area basis and classified by fuel use. The 27 point sources comprise

4 steam electric plants
4 industrial power plants
2 multiple-family residential heating plants
2 commercial heating plants
1 concrete batching plant
1 ferrous foundry
1 nonferrous foundry
1 petroleum refining catalytic cracker
1 petroleum refining sulfur recovery plant
1 sulfuric acid plant
1 iron and steel sintering plant
1 iron and steel blast furnace
1 iron and steel open hearth furnace (conventional)
1 iron and steel open hearth furnace (oxygen lance)

- 1 iron and steel basic oxygen furnace
- 1 iron and steel electric arc furnace
- 1 kraft pulp mill recovery furnace
- 1 kraft pulp mill lime kiln
- 1 municipal incinerator

The 20 area sources were made up of industrial, commercial, and multiple-family residential users of coal and residual oil.

To attain the second objective, automating the simulation, a complex computer program was written to carry out the multiple source computations under a number of different financial incentive schemes. The flow diagrams and FORTRAN IV listings of the program routines are given in Appendix B.

The third objective, applying the improved simulator, was met by using the computer program to analyze the costs of several strategies for achieving various abatement goals. Ten different schemes for subsidizing fixed and variable costs were analyzed.

The detailed discussion of the study below is organized the same as the Model City I discussion, in accordance with the general analytical concept outlined in Chapter I (see Exhibit I-1).

ANALYSIS

Inputs

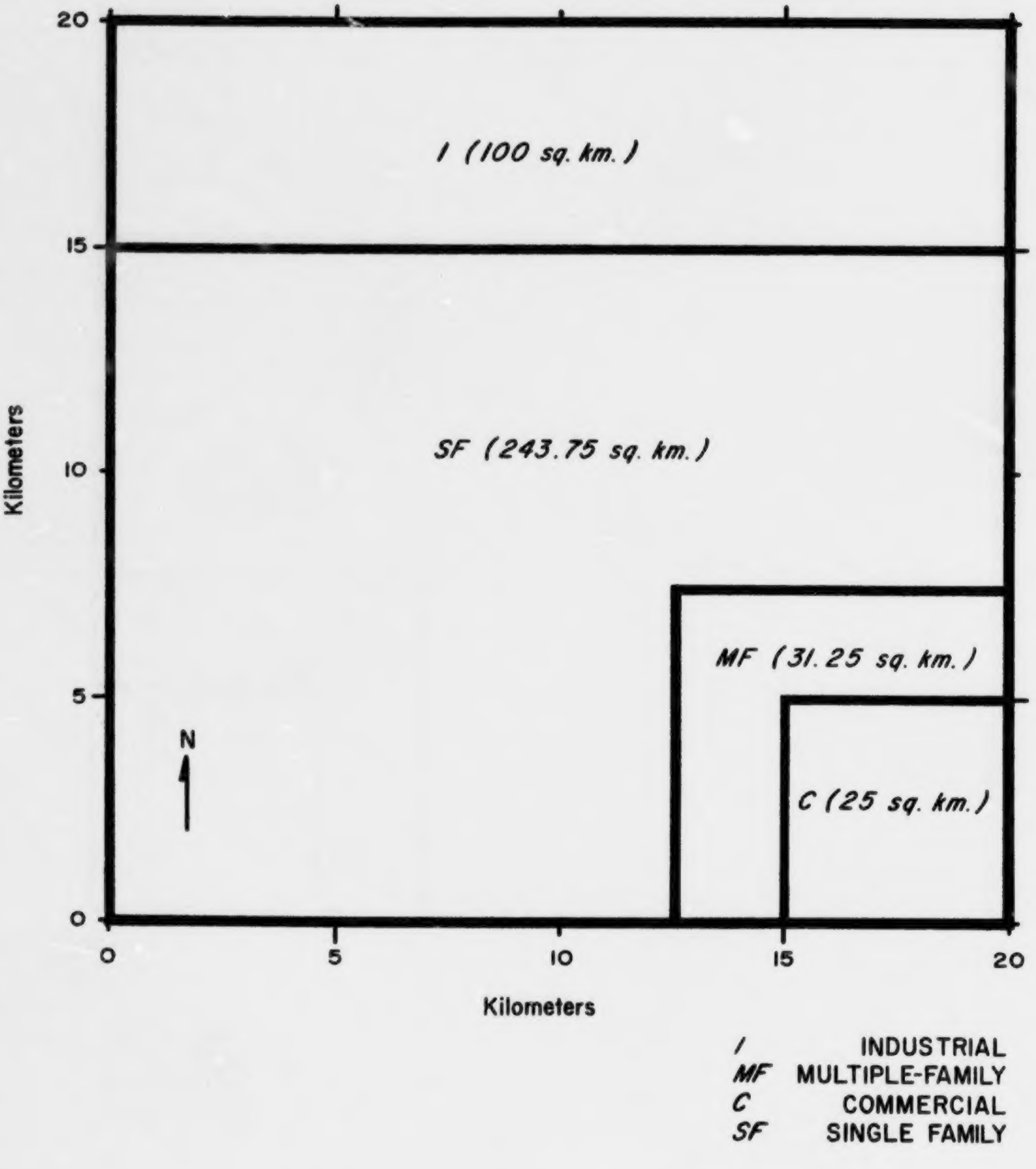
The inputs to begin this analysis and to use as data for the computer programs developed for this study are the physical properties of the city, the meteorological conditions of the city, and the emissions inventory. The physical layout of the model city simulated is given in Exhibit III-1. The point sources of the city are shown in Exhibit III-2. The principal characteristics of the model city - population, population density, housing density, etc. - which are necessary for calculating the extent of human exposure to pollutant emissions are provided in Exhibit III-3.

The Model City II study involved further development and sophistication of the model city used for demonstration purposes in the Model City I study. Different emission sources were specified. They include a wider variety of stationary combustion sources and certain process industries as well. These sources include more significant industrial sources of SO_x and SP. Exhibit III-4 is the assumed emissions inventory for the model city. The exhibit gives sources of emissions, stack heights, types of fuel and units, annual heat input, stack gas flow rate, and unabated SO_x and SP emissions. It was assumed that the SO_x and SP emissions resulted from the combustion of fossil fuels for heat generation and from process sources. As in the Model City I study, it was assumed that emissions from space heating of single family dwellings on the East Coast by 1970 would be negligible, and these emissions are ignored.

28

EXHIBIT III-1

GEOGRAPICAL LAYOUT OF MODEL CITY II

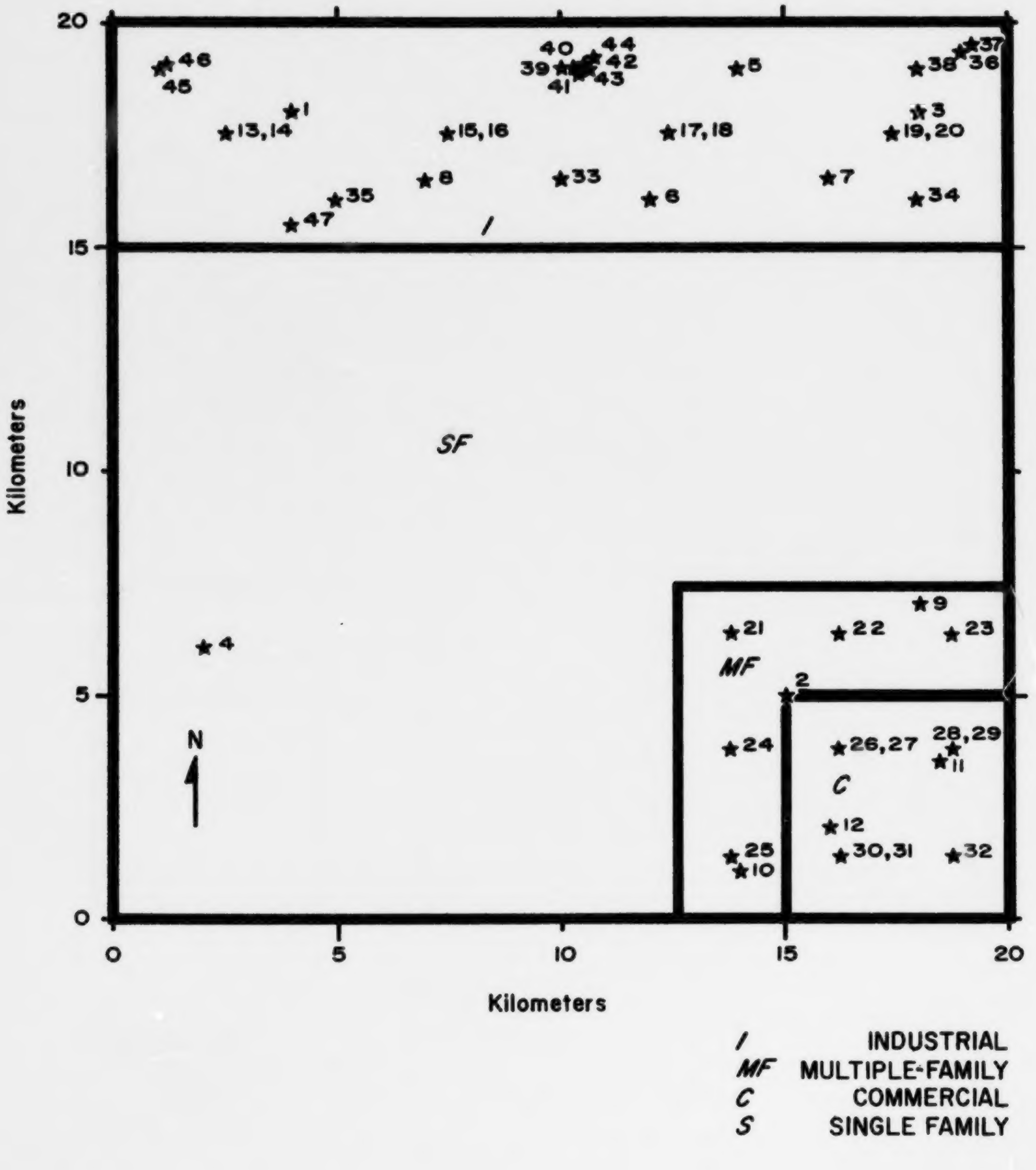


I (100 sq. km.)
SF (243.75 sq. km.)
MF (31.25 sq. km.)
C (25 sq. km.)
N
Kilometers
Kilometers
0
5
10
15
20
I INDUSTRIAL
MF MULTIPLE-FAMILY
C COMMERCIAL
SF SINGLE FAMILY

EXHIBIT III-2

LOCATION OF POINT SOURCES OF EMISSIONS IN MODEL CITY II

(See Exhibit III-4 for Source Number Descriptions)



20
15
10
5
0
0
5
10
15
20
Kilometers
Kilometers
46
45
40
44
39
42
41
43
5
38
37
36
1
3
13,14
15,16
17,18
19,20
8
33
7
35
6
34
47
I
SF
9
21
22
23
4
MF
2
N
24
26,27
28,29
11
C
12
25
10
30,31
32
I INDUSTRIAL
MF MULTIPLE-FAMILY
C COMMERCIAL
S SINGLE FAMILY

EXHIBIT III-3

PRINCIPAL CHARACTERISTICS OF MODEL CITY II

Total population	2,000,000
Employment:	
Industrial	440,000
Commercial	360,000
Number of entities/units:	
Industrial	8,000
Commercial	45,000
Single-family	428,570
Multiple-family	200,000
Number of people per	
Single-family unit	3.5
Multiple-family unit	2.5
Number of employees per	
Industrial entity	55
Commercial entity	8
Number of units/entities per square kilometer	
Single-family	1,758
Multiple-family	6,400
Industrial	80
Commercial	1,800
Size:	
Single-family area	243.75 sq. km.
Multiple-family area	31.25 sq. km.
Industrial area	100 sq. km.
Commercial area	25 sq. km.

Power plants:

The uptown plant in northeast area operates about 20 hours a day at a heat rate of about 7,000 Btu/kwh. Downtown plant in commercial area operates 21 hours a day at a heat rate of 8,000 Btu/kwh, and downtown in southwest operates about 14 hours a day at 2,000 Btu/kwh. Uptown plant in northwest area operates 24 hours/day at heat rate of 7,000 Btu/kwh.

Exhibit III-3, cont'd

Stack Heights:	
Power plants	
Uptown	
1. Northwest	160 meters
2. Northeast	80 meters
Downtown	
1. Southwest	100 meters
2. Southeast	80 meters
Indistrial (all same)	30 meters
Commercial (all same)	40 meters
Multiple-family (all same)	15 meters
Exposure densities (average number of people per square kilometer per day):*	
Single-family	5,265
Multiple-family	12,533
Commercial	7,120
Industrial	1,470

---

* Average length of work day is assumed to be eight hours. In addition, daily migration from the single and multiple-family sectors to the commercial sector has been assumed to involve 350,000 people with an average stay of four hours.

EXHIBIT III-4

MODEL CITY II SOURCES OF EMISSIONS

Source Number	Description	Stack Height (meters)	Fuel Type	Type of Furnace	Gross Annual Heat Input (10^{12} Btu)	Number of Units	Stack Gas Flow Unit (10^3 acfm)	Emissions (gm/sec) SO_x	SP
1	Power plant	160	Coal	Cyclone	44.1	4	450	1854.1	414.7
2	Power plant	100	Residual oil	Oil	42.0	4	500	1580.7	32.2
3	Power plant	80	Coal	Pulverized Dry Bottom	11.1	4	140	466.7	835.1
4	Power plant	80	N. Gas	Gas	9.9	N/R	N/R	0.1	2.1
5	Stationary combustion source-industrial	30	Coal	Pulverized Dry Bottom	50	1	1.5	2.1	3.2
6	Stationary combustion source-industrial	35	Coal	Pulverized Dry Bottom	100	1	3.1	4.2	6.5
7	Stationary combustion source-industrial	40	Coal	Pulverized Dry Bottom	300	1	9.4	12.6	19.4
8	Stationary combustion source-industrial	50	Residual oil	Oil	400	2	20.0	15.1	0.3
9	Stationary combustion source-multiple-family	20	Residual oil	Oil	10	1	1.3	0.4	0.0
10	Stationary combustion source-multiple-family	20	Residual oil	Oil	50	1	6.3	1.9	0.1
11	Stationary combustion source-commercial	66	Coal	Pulverized Dry Bottom	200	3	25.0	8.4	12.9
12	Stationary combustion source-commercial	60	Residual oil	Oil	300	4	37.5	11.3	0.2
13	Area source-industrial	30	Coal	N/A	1.125	N/A	N/A	47.3	72.8
14	Area source-industrial	30	Residual oil	N/A	6.75	N/A	N/A	254.0	7.8
15	Area source-industrial	30	Coal	N/A	1.125	N/A	N/A	47.3	72.8
16	Area source-industrial	30	Residual oil	N/A	6.75	N/A	N/A	254.0	7.8
17	Area source-industrial	30	Coal	N/A	1.125	N/A	N/A	47.3	72.8
18	Area source-industrial	30	Residual oil	N/A	6.75	N/A	N/A	254.0	7.8
19	Area source-industrial	30	Coal	N/A	1.125	N/A	N/A	47.3	72.8
20	Area source-industrial	30	Residual oil	N/A	6.75	N/A	N/A	254.0	7.8
21	Area source-multiple-family	20	Residual oil	N/A	1.2	N/A	N/A	45.2	1.4
22	Area source-multiple-family	20	Residual oil	N/A	1.2	N/A	N/A	45.2	1.4
23	Area source-multiple-family	20	Residual oil	N/A	1.2	N/A	N/A	45.2	1.4
24	Area source-multiple-family	20	Residual oil	N/A	1.2	N/A	N/A	45.2	1.4
25	Area source-multiple-family	20	Residual oil	N/A	1.2	N/A	N/A	45.2	1.4
26	Area source-commercial	40	Coal	N/A	0.734	N/A	N/A	30.9	1.4
27	Area source-commercial	40	Residual oil	N/A	5.625	N/A	N/A	236.5	47.5
28	Area source-commercial	40	Coal	N/A	0.734	N/A	N/A	30.9	6.5
29	Area source-commercial	40	Residual oil	N/A	5.625	N/A	N/A	236.5	47.5
30	Area source-commercial	40	Coal	N/A	0.734	N/A	N/A	30.9	6.5
31	Area source-commercial	40	Residual oil	N/A	5.625	N/A	N/A	236.5	6.5
32	Area source-commercial	40	Residual oil	N/A	5.625	N/A	N/A	236.5	6.5

33

Exhibit III-4, cont'd

Source Number	Description	Stack Height (meters)	Fuel Type	Type of Furnace	Annual Product Output (Input)	Number of Units	Stack Gas Flow Unit (10^3 acfm)	Emissions (gm/sec)	
								SO_x	SP
33	Concrete batching and cement silo	10	None for process	N/A	17,000 cu. yds. cement 36,600 cu. yds. aggregate(Input)	1 of each	0.750	0.0	0.1
34	Ferrous foundry-grey iron cupola	30	Coke	N/A	17,950 tons iron (Input)	1	13.0	0.6	4.8
35	Nonferrous foundry-lead cupola and	20	Coke	N/A	214 tons Coke (Input)	1			
	lead reverberatory furnace	30	#4 Oil	N/A	150,000 gallons #4 Oil (Input)	1	13.0	7.9	17.2
36	Petroleum refinery-catalytic cracker	30	Coke	N/A	41 X 10^6 barrels	1	77.5	0.0	37.8
37	Petroleum refinery-sulfur recovery system	30	None for process	N/A		1	40.0	177.3	0.0
38	Sulfuric acid plant	30	None for process	N/A	172,500 tons	1	38.5	136.3	8.4
39	Iron and steel mill-sintering plant	0	N. Gas	N/A		2	513.0	0.0	863.8
40	Iron and steel mill-blast furnace	35	Coke	N/A		4	205.0	558.0	8637.7
41	Iron and steel mill-conventional open hearth furnace	20	N/A	N/A	3.0 x 10^6 tons	2	96.0	0.0	15.6
42	Iron and steel mill-oxygen lance open hearth furnace	20	N/A	N/A		8	31.5	0.0	155.3
43	Iron and steel mill-basic oxygen furnace	30	N/A	N/A		2	300.0	0.0	863.8
44	Iron and steel mill-electric arc furnace	20	N/A	N/A		3	720.0	0.0	90.8
45	Kraft mill-recovery furnace	80	By-product of chemical process	N/A	262,500 tons pulp	1	312.0	0.0	591.1
46	Kraft mill-lime kiln	40	N. Gas	N/A		1	52.0	0.0	73.7
47	Municipal incinerator	75	N. gas	N/A	143,000 tons refuse	2	236.0	9.4	592.4

N/A - Not applicable

N/R - Not required

Meteorological Analysis

The computerized meteorological diffusion model used in the Model City I study was also used for this study to compute the average (mean) annual ground-level concentration at each receptor point. The hypothetical wind data used as meteorological input to this program was the same as that used in the Model City I study. The emissions inventory given in Exhibit III-4 along with the grid coordinates of the points were the additional inputs to this program to compute the pre-abatement concentrations of SO_x at the 28 receptor points. Exhibit III-5 shows the pre-abatement SO_x concentration at each receptor point. The concentration at any point is simply the sum of the concentrations contributed to that point by the 47 point and area sources. Pre-abatement particulate concentrations at the receptor points were not computed; for each abatement strategy the bonus reduction in particulates was computed as a percent reduction and as an absolute reduction.

Abatement Analysis

In this study the list of available control technologies considered in the Model City I study was extended to include fuel switching and most types of available control equipment. Fuel switching is defined as the replacement of the present fuel with a fuel of another type. Fuel switching from coal to low sulfur fuel oil or to natural gas and from residual fuel oil to natural gas were permitted for some of the sources in this model. In addition to fuel switching and substitution, stack gas cleaning and the following air pollution control equipment were available options in the analysis of pollution control methods:

> Mechanical collectors - These devices depend on gravity, centrifugal force, or vortices to collect particulate matter. This type of equipment includes cyclone settling chambers, baffled chambers, louvered chambers, and devices in which the carrier gas-particulate matter mixture passes through a fan in which separation occurs.
>
> Wet scrubbers - These are devices in which the prime means of collection is a liquid introduced into the collector for contact with the aerosol.
>
> Electrostatic precipitators - This equipment employs the principle of particle ionization by a discharge electrode and then entrapment by a collecting plate consisting of a grounded electrode.
>
> Fabric filters - Filters remove particulate matter from gas streams by retention of the particles in or on a porous structure through which the gas flows.

EXHIBIT III-5

PRE-ABATEMENT SOx CONCENTRATIONS AT EACH RECEPTOR POINT

(parts per million, ppm)

Receptor Point	SO_x Concentration
1	0.025
2	0.074
3	0.107
4	0.066
5	0.030
6	0.052
7	0.064
8	0.062
9	0.023
10	0.037
11	0.015
12	0.022
13	0.064
14	0.089
15	0.076
16	0.059
17	0.062
18	0.093
19	0.103
20	0.095
21	0.042
22	0.060
23	0.120
24	0.122
25	0.026
26	0.050
27	0.064
28	0.090

36

Spray chambers - Spray nozzles are employed to send the gas stream through a chamber. As the velocity of the stream decreases, the wetted particles settled and are collected at the bottom of the chamber.

Sulfur recovery facilities - Crude oil derivatives enter the sulfur recovery plant in a gas stream. They pass through a series of converters and condensers where most of the sulfur is removed and the remainder is converted to sulfur dioxide and diluted with air, then the efluent gases are discharged into the atmosphere.

Wire mesh mist eliminators - These devices employ two chambers in which the lower stage is much denser than the upper and acts as a coalescer.

Not all these options and technologies were available to each of the sectors in this study. Exhibit III-6 gives the emission control technologies available to each source.

Cost Analysis

The cost of individual control technologies and the permitted combinations of technologies for each source were computed manually from formulas given in Appendix C, except that depreciation, interest, and other capital charges were not included in the Model City II study. These computations give the high, mean, and low annual cost of each technology. These individual costs and compatible combinations of technology were used as input to the computer program which calculated the annual cost of each control state (combination of several compatible control technologies) and the high and low cost variances. It should be stressed that these costs are intended to be representative only of costs which might be encountered in practice.

Following is a discussion and the estimated costs of the four generic types of control technologies considered in this study:

(1) Fuel substituting and switching
(2) Mechanical control devices for particulate emissions
(3) SO_x stack gas cleaning systems
(4) Municipal incineration

Fuel Substitution and Switching - Exhibit III-7 shows the cost of converting from coal to oil/gas burners. Costs are given in three cost ranges: low, high, and median. Costs include the removal of the old boiler, installation of a new boiler, and the cost of installing an oil storage tank(s) with sufficient capacity to service the boiler.

The boiler is assumed to have the following characteristics: good quality, automatic convertibility from #2 oil to gas, and capability of handling pressures of 125 to 150 pounds per square inch for process use and 15 to 30 pounds per square inch on the small boilers for space heating.

38

EXHIBIT III-6

AVAILABILITY OF TECHNIQUES FOR SO_x AND SP CONTROL

Source Number	Description	Fuel Sub.		Fuel Switch,		Control							
		Coal	Resid. Oil	Natural Gas	Resid. Oil	Stack Gas Cleaning	Cyclone	EP	Fabric Filter	Scrubbers	Sulfur Recovery System	Mist Eliminator	Spray Cleaner
1	Power plant	A			A	A	A	A					
2	Power plant		A			A	A	A					
3	Power plant	A		A	A		A	A					
4	Power plant												
5	Stationary combustion source-industrial	A		A	A								
6	Stationary combustion source-industrial	A		A	A								
7	Stationary combustion source-industrial	A		A	A		A						
8	Stationary combustion source-industrial		A	A			A						A
9	Stationary combustion source-multiple-family		A	A									
10	Stationary combustion source-multiple-family		A	A									
11	Stationary combustion source-commercial	A		A	A		A						
12	Stationary combustion source-commercial		A	A			A						
13	Area source-industrial	A											
14	Area source-industrial		A										
15	Area source-industrial	A											
16	Area source-industrial		A										
17	Area source-industrial	A											
18	Area source-industrial		A										
19	Area source-industrial	A											
20	Area source-industrial		A										
21	Area source-multiple-family		A										
22	Area source-multiple-family		A										
23	Area source-multiple-family		A										
24	Area source-multiple-family		A										
25	Area source-multiple-family		A										
26	Area source-commercial	A											
27	Area source-commercial		A										
28	Area source-commercial	A											
29	Area source-commercial		A										
30	Area source-commercial	A											
31	Area source-commercial		A										
32	Area source-commercial		A										
33	Concrete batching-cement silo								A				
34	Ferrous foundry-gray iron cupola						A	A	A	A			
35	Nonferrous foundry-head cupola and lead reverberatory furnace		A	A					A				
36	Petroleum refinery-catalytic cracker							A					
37	Petroleum refinery-sulfur recovery system										A		
38	Sulfuric acid plant									A		A	

Source Number	Description	Fuel Sub.		Fuel Switch.		Control							
		Coal	Resid. Oil	Natural Gas	Resid. Oil	Stack Gas Cleaning	Cyclone	EP	Fabric Filter	Scrubbers	Sulfur Recovery System	Mist Eliminator	Spray Cleaner
39	Iron and steel mill-sintering plant						A	A					
40	Iron and steel mill-blast furnace						A	A		A			
41	Iron and steel mill-conventional open -hearth furnace							A	A	A			
42	Iron and steel mill-oxygen lance open hearth furnace							A	A	A			
43	Iron and steel mill-basic oxygen furnace							A		A			
44	Iron and steel mill-electric arc-furnace							A	A	A			
45	Kraft mill-recovery furnace							A		A			
46	Kraft mill-lime kiln									A			
47	Municipal incinerator						A	A	A	A			A

EP - Electrostatic precipitator
A - Available
Blank indicates not applicable

EXHIBIT III-7

ESTIMATED CAPITAL COSTS FOR BOILER CONVERSION

Boiler H.P.	Total Conversion Costs (000's)		
	Low Range	Median Range	High Range
50	$21.8	$26.7	$31.7
100	28.5	34.8	41.2
200	42.6	51.5	60.4
300	57.1	68.7	80.2
400	69.3	83.4	97.5

Installation costs include all necessary piping and labor to install the unit as well as all costs associated with transportation of the boiler to its destination. The low range of installation costs assumes an average installation with moderate assemblage at destination site. The high range assumes a difficult installation, perhaps necessitating a new concrete floor and the temporary removal of a wall. Storage tank installation costs assume that the tank can be installed in the ground adjacent to the building in which the boiler is housed.

The cost of converting a present oil burning boiler into one that will burn gas on either a firm or interruptible basis has been estimated as one-half the cost of a complete new boiler.

The median cost range for boiler conversions has been used in calculating the costs for each source.

The costs of coal and oil to different user categories, the percent sulfur and ash content, and the heat content are given in Exhibit III-8. Prices are estimated for high, average, and low costs. Corresponding costs for natural gas are given in Exhibit III-9.

Mechanical Control Device Costs - Exhibits III-10 through III-13 show the estimated purchase costs of cyclone collectors, wet scrubbers, electrostatic precipitators, and fabric filters (baghouses). Costs are given in terms of dollars per actual cubic feet per minute gas throughput. Sizes (capacities) of the control devices are stated in terms of thousands of actual cubic feet per minute gas throughput. Low, median, and high cost ranges are indicated.

The low cost ranges represent units of mild steel construction with a less efficient level of particulate control than is available in the high cost range. The high cost ranges represent more complicated, higher efficiency devices, usually built of materials which will withstand corrosion and excessive abrasion.

40

EXHIBIT III-8

FUEL COSTS (OIL AND COAL)
(cents per million Btu)

User	Fuel	Percent		Heat Content	Cost		
		Sulfur	Ash	(Btu)	Low	Median	High
Power plants							
	Residual oil	2.5	Neg.	150 x 10^3/gal	30.0	31.5	34.0
		2.0	Neg.	148 x 10^3/gal	30.0	33.0	34.0
		1.5	Neg.	146 x 10^3/gal	34.0	35.0	36.0
		1.0	Neg.	144 x 10^3/gal	37.5	39.5	41.5
		0.5	Neg.	142 x 10^3/gal	-	44.0	-
	Coal	2.0	8.5	26 x 10^6/ton	28.0	30.0	32.5
		1.5	8.25	26 x 10^6/ton	28.0	31.0	32.5
		1.0	7.0	26 x 10^6/ton	36.5	38.0	41.5
		0.5	5.0	26 x 10^6/ton	42.5	45.5	48.5
Industrial							
	Residual oil	2.5	Neg.	150 x 10^3/gal	31.5	35.0	36.5
		2.0	Neg.	148 x 10^3/gal	31.5	36.0	36.5
		1.5	Neg.	146 x 10^3/gal	34.0	37.0	38.0
		1.0	Neg.	144 x 10^3/gal	37.5	41.5	43.5
		0.5	Neg.	142 x 10^3/gal	44.0	45.0	46.0
	Coal	2.0	9.0	26 x 10^6/ton	33.0	35.0	37.0
		1.5	8.5	26 x 10^6/ton	34.0	35.0	37.0
		1.0	7.0	26 x 10^6/ton	43.0	46.0	48.0
		2.5	5.0	26 x 10^6/ton	49.0	52.0	55.0
Multiple-family and commercial							
	Residual oil	2.5	Neg.	150 x 10^3/gal	32.0	33.5	36.5
		2.0	Neg.	148 x 10^3/gal	32.0	35.5	36.5
		1.5	Neg.	146 x 10^3/gal	36.0	37.0	38.0
		1.0	Neg.	144 x 10^3/gal	39.5	41.0	43.5
		0.5	Neg.	142 x 10^3/gal		46.0	
	Coal	2.0	9.0	26 x 10^6/ton	37.0	44.0	51.0
		1.5	8.5	26 x 10^6/ton	37.0	49.0	51.0
		1.0	7.0	26 x 10^6/ton	46.0	54.0	62.0
		0.5	5.0	26 x 10^6/ton	54.0	62.0	70.0
Any							
	Distillate #4	1.5	Neg.	145 x 10^3/gal	46.5	50.0	55.0
		1.0	Neg.	145 x 10^3/gal	48.0	52.0	57.5
	#2	0.5	Neg.	141 x 10^3/gal	71.0	74.0	78.0

EXHIBIT III-9

NATURAL GAS COSTS
(cents per million Btu)

User	Service	Annual Use (10^9 Btu)	Cost		
			Low	Median	High
Power Plant			35.5	40.0	47.5
Industrial	Firm	50	79.0	122.0	165.0
		100	79.0	122.0	165.0
		200	78.0	121.5	165.0
		300	78.0	121.5	165.0
		400	78.0	121.5	165.0
	Interruptible	50	50.0	57.0	64.0
		100	45.0	51.0	57.0
		200	44.0	49.0	54.0
		300	34.0	44.0	54.0
		400	34.0	44.0	54.0
Multiple-family and commercial					
	Firm	50	80.0	108.0	156.0
		100	80.0	108.0	156.0
		200	80.0	108.0	156.0
		300	80.0	108.0	156.0
		400	80.0	108.0	156.0
	Interruptible	50	50.0	70.0	90.0
		100	43.0	66.5	90.0
		200	42.0	66.0	90.0
		300	41.0	65.0	90.0
		400	40.0	65.0	90.0

Neg. = assumed to be neglegible for this study.

EXHIBIT III-10

COST OF CYCLONE COLLECTORS

Capacity (acfm)	Purchase Cost ($/acfm) Efficiency			Operating Cost ($/hour) Efficiency			Maintenance Cost ($/year) Hours of Operation		
	Low	Med	High	Low	Med	High	Less Than 2,000 Hours	2,000-6,000 Hours	More Than 6,000 Hours
5	0.27	0.54	0.80	0.01	0.03	0.05	25.00	75.00	125.00
10	0.20	0.40	0.60	0.03	0.06	0.10	50.00	150.00	250.00
15	0.17	0.33	0.50	0.04	0.09	0.15	75.00	225.00	375.00
20	0.14	0.27	0.40	0.05	0.13	0.20	100.00	300.00	500.00
25	0.10	0.20	0.30	0.06	0.16	0.25	125.00	375.00	625.00
50	0.10	0.20	0.30	0.13	0.31	0.50	250.00	750.00	1,250.00
75	0.10	0.20	0.30	0.19	0.47	0.76	375.00	1,125.00	1,875.00
100	0.10	0.20	0.30	0.25	0.63	1.01	500.00	1,500.00	2,500.00
200	0.10	0.20	0.30	0.50	1.25	2.02	1,000.00	3,000.00	5,000.00
300	0.10	0.20	0.30	0.76	1.88	3.02	1,500.00	4,500.00	7,500.00
400	0.10	0.20	0.30	1.01	2.51	4.03	2,000.00	6,000.00	10,000.00
500	0.10	0.20	0.30	1.26	3.14	5.04	2,500.00	7,500.00	12,500.00
750	0.10	0.20	0.30	1.89	4.70	7.56	3,750.00	11,250.00	18,750.00
1,000	0.10	0.20	0.30	2.52	6.27	10.08	5,000.00	15,000.00	25,000.00

EXHIBIT III-11

COST OF WET SCRUBBERS

Capacity (acfm)	Purchase Cost ($/acfm) Efficiency			Operating Cost ($/hour) Efficiency			Maintenance Cost ($/year) Hours of Operation		
	Low	Med	High	Low	Med	High	Less Than 2,000 Hours	2,000-6,000 Hours	More Than 6,000 Hours
5	0.30	0.75	1.20	0.09	0.31	0.53	100.00	200.00	300.00
10	0.25	0.63	1.00	0.19	0.62	1.06	200.00	400.00	600.00
15	0.20	0.50	0.80	0.28	0.94	1.59	300.00	600.00	900.00
20	0.19	0.46	0.70	0.37	1.25	2.12	400.00	800.00	1,200.00
25	0.16	0.40	0.64	0.46	1.56	2.66	500.00	1,000.00	1,500.00
50	0.13	0.31	0.50	0.93	3.18	5.31	1,000.00	2,000.00	3,000.00
75	0.10	0.25	0.40	1.40	4.68	7.97	1,500.00	3,000.00	4,500.00
100	0.10	0.25	0.40	1.86	6.24	10.62	2 000.00	4,000.00	6,000.00
200	0.10	0.25	0.40	3.72	12.48	21.24	4,000.00	8,000.00	12,000.00
300	0.10	0.25	0.40	5.58	18.72	31.86	6,000.00	12,000.00	18,000.00
400	0.10	0.25	0.40	7.44	24.96	42.48	8,000.00	16,000.00	24,000.00
500	0.10	0.25	0.40	9.30	31.20	53.10	10,000.00	20,000.00	30,000.00
750	0.10	0.25	0.40	13.95	46.80	79.65	15,000.00	3,000.00	45,000.00
1,000	0.10	0.25	0.40	18.60	62.40	106.20	20,000.00	40,000.00	60,000.00

EXHIBIT III-12

COST OF ELECTROSTATIC PRECIPITATORS

Capacity (acfm)	Purchase Cost ($/acfm)			Operating Cost ($/hour)			Maintenance Cost ($/year) Hours of Operation		
	Efficiency			Efficiency					
	Low	Med	High	Low	Med	High	Less Than 2,000 Hours	2,000-6,000 Hours	More Than 6,000 Hours
5	1.50	2.25	3.00	0.01	0.01	0.01	50.00	100.00	150.00
10	1.25	1.88	2.50	0.01	0.02	0.03	100.00	200.00	300.00
15	1.13	1.70	2.25	0.02	0.03	0.04	150.00	300.00	450.00
20	1.00	1.50	2.00	0.03	0.04	0.05	200.00	400.00	600.00
25	0.90	1.35	1.80	0.04	0.05	0.06	250.00	500.00	750.00
50	0.65	0.98	1.30	0.07	0.10	0.13	500.00	1,000.00	1,500.00
75	0.50	0.75	1.00	0.11	0.15	0.19	750.00	1,500.00	2,250.00
100	0.38	0.56	0.75	0.14	0.20	0.25	1,000.00	2,000.00	3,000.00
200	0.35	0.53	0.70	0.28	0.40	0.50	2,000.00	4,000.00	6,000.00
300	0.32	0.48	0.63	0.42	0.60	0.75	3,000.00	6,000.00	9,000.00
400	0.29	0.44	0.58	0.56	0.80	1.00	4,000.00	8,000.00	12,000.00
500	0.26	0.39	0.51	0.70	1.00	1.25	5,000.00	10,000.00	15,000.00
750	0.22	0.33	0.43	1.05	1.50	1.88	7,500.00	15,000.00	22,500.00
1,000	0.22	0.33	0.43	1.40	2.00	2.50	10,000.00	20,000.00	30,000.00

EXHIBIT III-13

COST OF FABRIC FILTERS

Capacity (acfm)	Purchase Cost ($/acfm) Efficiency			Operating Cost ($/hour) Efficiency			Maintenance Cost ($/year) Hours of Operation		
	Low	Med	High	Low	Med	High	Less Than 2,000 Hours	2,000-6,000 Hours	More Than 6,000 Hours
5	0.50	1.00	1.50	0.01	0.03	0.05	100.00	250.00	400.00
10	0.45	0.90	1.35	0.03	0.06	0.10	200.00	500.00	800.00
15	0.40	0.80	1.20	0.04	0.10	0.15	300.00	750.00	1,200.00
20	0.30	0.60	0.90	0.05	0.13	0.20	400.00	1,000.00	1,600.00
25	0.25	0.50	0.75	0.06	0.16	0.25	500.00	1,250.00	2,000.00
50	0.20	0.40	0.60	0.13	0.31	0.50	1,000.00	2,500.00	4,000.00
75	0.20	0.40	0.60	0.19	0.47	0.76	1,500.00	3,750.00	6,000.00
100	0.20	0.40	0.60	0.25	0.63	1.01	2,000.00	5,000.00	8,000.00
200	0.20	0.40	0.60	0.50	1.25	2.02	4,000.00	10,000.00	16,000.00
300	0.20	0.40	0.60	0.76	1.88	3.02	6,000.00	15,000.00	24,000.00
400	0.20	0.40	0.60	1.01	2.51	4.03	8,000.00	20,000.00	32,000.00
500	0.20	0.40	0.60	1.26	3.13	5.04	10,000.00	25,000.00	40,000.00
750	0.20	0.40	0.60	1.89	4.70	7.56	15,000.00	37,500.00	60,000.00
1,000	0.20	0.40	0.60	2.52	6.27	10.08	20,000.00	50,000.00	80,000.00

Installation costs may vary depending on the complexity of the installation and the state of assemblage in which the unit is shipped. A major installation cost variance occurs when units must be placed off the ground and a substantial amount of additional materials and labor expense are required.

Operating costs include power, labor, and, where applicable, water and additives (catalysts). Maintenance costs include cleaning the devices on a regular basis and replacing worn parts.

Costs were developed from conversations and correspondence with various industry and government officials and from published literature (references 1 through 38).

SO_2 Stack Gas Cleaning: Capital Costs - A report by Sidney Katell 39/ states that the alkalized alumina process has a capital cost of $7.95 million in an 800 MW power plant, excluding the original need for working capital, but including initial catalyst requirements. After conversation with several individuals familiar with the process, it was decided that to ensure a reasonable estimate, it would be desirable to add 25 percent to the original estimate; thus, a capital cost of $10 million was derived. For a 200 MW plant a proportionate capital cost of $2.5 million was used.

The $10 million and $2.5 million costs were then divided by 15 to derive an annual cost on a 15-year straight-line depreciation basis. To the annual cost was added the annual capital cost of an electrostatic precipitator and cyclone, per Exhibits III-10 and III-12. Exhibit III-14 shows the annual SO_2 stack gas cleaning costs developed for power plants 1, 2, and 3.

EXHIBIT III-14

ALKALIZED ALUMINA
SO_2 STACK GAS CLEANING
FOR POWER PLANTS 1,2,3

	Power Plant No.		
	1	2	3
Megawatt size	800	800	200
Capital cost of SO_2 stack gas cleaning	$10,000,000	$10,000,000	$12,500,000
Annual capital cost	666,667	666,667	166,667
Annual capital cost of 99.5% electrostatic precipitator/ cyclone	156,800	167,800	59,900
Total annual capital cost	823,467	834,467	226,567
Annual operating cost of stack gas cleaning	2,719,600	2,719,600	679,900
Annual operating cost of 99.5% electrostatic precipitator/ cyclone	237,800	242,200	66,700
	2,957,400	2,961,800	746,600
TOTAL ANNUAL COST	$ 3,780,867	$ 3,796,267	$ 973,167

SO$_2$ Stack Gas Cleaning: Operating and Maintenance Costs - As shown in Exhibits III-14 and III-15, the alkalized alumina process, developed by the Bureau of Mines, is applied to both a 200 MW and an 800 MW power plant operating approximately 8,000 hours a year.

The operating and maintenance costs include those of direct materials (catalyst, power, and water), direct labor, plant maintenance, payroll overhead, operating supplies, and administrative and general overhead. The costs for the 200 MW plant are 25 percent of the cost of the 800 MW plant.

Municipal Incinerator Control Device Applications - The municipal incinerator on which the various devices are installed utilizes two 250-ton-a-day continuous feed type refractory furnaces with mechanical stokers. The furnaces operate 5 1/2 days a week, 24 hours a day, 52 weeks a year. They have a dust loading of 3.5 pounds of dust per 1,000 pounds of flue gas corrected to 50 percent excess air. The gas temperature entering the control device is 80°F. Gas volume is 236,000 acfm.

The control devices applied are a baffled spray chamber and a baffled spray chamber in combination with a cyclone, wet scrubber, electrostatic precipitator, and fabric filter, operating at efficiency levels of 50, 78, 96, 95, and 99+percent, respectively. Exhibit III-16 shows the estimated cost of installing various pollution control devices on the municipal incinerator described above.

Annual operating costs assume water costs of $0.20 per 1,000 gallons and power costs of $0.0075 kwh.

Final Analysis

Two different abatement strategies were applied in the analysis of air pollution control in Model City II - the equiproportional strategy and the least cost strategy. Computer programs were written to simulate these strategies and analyze the results of these alternatives. The equiproportional strategy (EP) is the minimum cost combination of emission controls which achieves at least the same given percentage emission reduction at each of the 47 emission point sources. The least cost strategy (LC) is the minimum cost combination of emission controls which achieves at least the stipulated abatement effectiveness.

Either of these strategies can be applied to achieve a particular abatement objective. For this study three abatement objectives or measures of effectiveness were considered:

(1) Reduction in total urban emissions
(2) Reduction in the concentration below a given level at each of the receptor points
(3) Reduction in total human exposure

EXHIBIT III-15

COST OF SO_2 STACK GAS CLEANING SYSTEM POWER PLANT WITH ALKALIZED ALUMINA [a]

(operating 8,000 hr/yr)

Direct cost	800 MW	200 MW[b]
Absorbent makeup $0.25 lb.	$ 900,000[c]	$225,000
Coal $7.80/ton	936,000[d]	234,000
Power $0.0075 kw/hr	114,000[e]	28,500
Heat $0.20 MMBtu	124,400[f]	31,100
Water $0.20 Mgal	52,800[g]	13,200
Direct labor		
365 days/yr; $2.75 man-hour	72,300	18,075
Supervision, 15% of labor	10,300	2,575
Plant maintenance		
$6,000 man/yr	138,000	34,500
Supervision, 20% of maint-labor	27,600	6,900
Material	69,000	17,250
Payroll overhead, 18.5% of payroll	46,000	11,500
Operating supplies, 20% of plant maintenance	46,900	11,725
TOTAL DIRECT COST	2,537,300	634,325
Indirect cost (admin & genl), 50% labor, maint, & supplies	182,300	45,575
TOTAL OPERATING COST	$2,719,600	$679,900

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[a] "Removing Sulfur Dioxide from Flue Gases", Sidney Katell, Chem Engrg Progress, October 1966, pp. 67-73.

[b] The costs for the 200 MW plant are 25 percent of the 800 MW plant costs. According to reference 39 there is a linear relationship.

[c] $0.625 per 1,000 scfm flue gas

[d] 15 tons/hr; $0.30 MMBtu

[e] 1,900 kw/hr

[f] 78,560,000 Btu/hr

[g] 33 M/gal/hr

EXHIBIT III-16

MUNICIPAL INCINERATOR CONTROL COSTS
(thousands)

	Refractory Furnaces; 2 at 250 tons/day; 230,000 acfm									
	Baffled Spray Chambers		Spray Chamber and Cyclone		Wet Scrubber		Spray Chamber & Electrostatic Precipitator		Spray Chamber Fabric Filter	
Purchase and Installation Cost	$188.2		$265.4		$400.9		$470.1		$699.5	
Capitalized Cost (15 year basis)		12.5		17.7		26.7		31.3		46.6
Operating Costs (annual):										
Power ($0.0075 kwh)	2.4		23.1		39.5		16.0		28.7	
Water ($0.20 Mgal)	21.8		19.9		39.0		19.9		23.0	
Maintenance	23.7		11.5		16.8		11.5		38.7	
		47.9		54.5		95.3		47.4		90.4
Totals		$60.4		$72.2		$122.0		$78.7		$137.0
Efficiency	50%		78%		96%		95%		99+%	
Pressure Drop (inches water)	0.4		0.25		6.0		0.25		5.0	

Furnace Data:

- Furnaces are continuous feed type with mechanical stokers.
- Dust loading: 3.5 lbs of dust per 1,000 lbs flue gas corrected to 50% excess air.
- Gas temperature entering control device: 150^{o}- 165^{o}F.
- Plant operates 5 1/2 days a week, 24 hrs a day, 52 weeks a year.
- Water/air ratio: 70/30.

Since the analysis of the results of applying either of the two strategies to each of the abatement objectives at each computation point becomes quite complex, computer programs were developed to select the optimal control technique to achieve the objective, compute the cost of implementing the strategy, and compute the resulting emissions reduction. Flow charts detailing the process of analysis in these programs are shown in Appendix C. The use of computers to simplify the computations permitted extension of the analysis to consider the abatement of two pollutants - SO_2 and particulates - instead of just one, as in the Model City I study. As the methods of reducing two pollutants differ greatly, the least cost strategy for reducing SO_2 emissions will most likely not be the same as the least cost strategy for reducing particulate emissions. Thus, the least cost solutions for reducing SO_x and particulate cannot be solved simultaneously. Therefore, it is necessary first to find the least cost solution to reducing one of the pollutants, then to solve for the additional control techniques to reduce the other pollutant below the stipulated level. In this study the optimal solution for reducing SO_2 emissions to a certain level was found first; additional controls were then applied to achieve at least a 20, 40, 60, 80, or maximum percent reduction in particulates at each of the calculation points for SO_2 emissions reduction.

Another new alternative analyzed in this study was the effect of incentive schemes in the form of subsidies for the fixed, variable, or total cost of air pollution controls employed by the sources. The incentive schemes considered are shown in Exhibit III-17. For each of these incentive schemes the least cost solution found was the least cost to the private sector to meet the abatement goal.

EXHIBIT III-17

TAX INCENTIVES SIMULATED

	Percent Credit Against	
Incentive Number	Fixed Costs	Variable Costs
1	0	0
2	7	0
3	20	0
4	40	0
5	7	7
6	7	20
7	7	40
8	20	20
9	40	40

COST-EFFECTIVENESS RESULTS

The equiproportional and least cost strategies were simulated to achieve the levels of abatement stipulated for each measure of effectiveness - reduction of SO_2 and particulate emissions, reduction of human exposure, and reduction of SO_2 concentration.

51

(1) Reduce SO_2 emissions by at least 20, 40, 60, 80, and maximum percent and reduce particulate emissions by at least 20, 40, 60, 80, and maximum percent.

- Equiproportional strategy: Exhibits III-18 through III-23 show for each calculation point and for each nominal particulate objective the average annual emissions (in grams/sec.) of SO_2 and particulate and the total estimated annual cost. By a calculation point is meant that at least the nominal percentage - 20, 40, etc. - reductions in SO_x must be achieved by the strategy. The costs given in that table are the costs to the private sector without support from the government (incentive no. 1). Note that in the first column, first row of Exhibit III-18 there is a savings, a negative cost of $5,100, to produce lower SO_2 and particulate emissions. This savings results from the fact that there exist fuels that are both cheaper and cleaner than the source is currently using. The costs to the private sector when there are incentive schemes in the form of government subsidies can easily be computed by the formula I = (1.00 - incentive rate/100) x Cost. This cost, I, is the government cost and is subtracted from the total cost to obtain the private cost.
- Least cost strategy: Exhibits III-24 through III-29 show for the least cost strategy information similar to that given in Exhibits III-18 through III-23 for the equiproportional strategy.
- Difference in cost and relative efficiency of EP and LC strategies: Exhibit III-30 shows that there is a difference in cost of almost $6 million between the EP and LC strategies for an 80 percent reduction in SO_2 and at least an 80 percent reduction in particulate emissions. Maximum reduction necessarily costs the same for any strategy.

52

EXHIBIT III-18

AGGREGATE EQUIPROPORTIONAL CURVE FOR REDUCTION OF SO_2 EMISSIONS AND REDUCTION OF HUMAN EXPOSURE TO SO_2

(NO TAX INCENTIVE)

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(0%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	32.1	49.7	77.0	79.5	83.3
Absolute reduction (gms/sec)	0.9	2,346.4	3,637.2	5,632.8	5,817.1	6,097.6
SO_2 Exposures						
Percent reduction	0.0	34.0	52.3	77.5	78.6	81.7
Absolute reduction (p-ppm)	22.2	38,360.3	58,995.3	87,360.1	88,638.1	92,151.7
Private Costs (000's)						
Fixed	$ 15.9	$ 41.9	$ 52.4	$ 1,711.7	$ 1,732.2	$ 1,726.2
Variable	-21.0	3,741.3	10,759.2	14,525.4	14,884.1	26,810.3
Process change	-5.1	17.5	2,810.0	1,132.8	1,397.1	8,267.3
Waste treatment	0.0	25.5	25.5	7,640.5	7,640.5	7,640.5
Fuel substitution	0.0	3,740.2	7,976.1	7,463.8	7,378.7	12,628.7
Total private cost	-5.1	3,783.2	10,811.6	16,237.1	16,416.3	28,536.5
Unit Cost of Reducing						
SO_2 emissions ($x1000/gm/sec)	5.775	1.612	2.973	2.883	2.882	4.680
SO_2 exposure ($x1000/p-ppm)	-0.230	0.099	0.183	0.186	0.185	0.310
Marginal Private Cost of Reducing						
SO_2 emissions ($x1000/gm/sec)		1.615	5.445	2.719	0.972	43.206
SO_2 exposure ($x1000/p-ppm)		0.099	0.341	0.191	0.140	3.450
Bonus Reduction in Particulate Emissions						
Percent reduction	0.1	0.6	9.8	11.0	11.0	11.0
Absolute reduction (gms/sec)	12.8	83.0	1,352.5	1,512.7	1,519.8	1,521.9

EXHIBIT III-19

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 20.0 PERCENT

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(0%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	32.1	49.7	77.0	79.5	83.3
Absolute reduction (gms/sec)	0.9	2,346.4	3,637.2	5,632.8	5,817.1	6,097.6
SO_2 Exposures						
Percent reduction	0.0	34.0	52.3	77.5	78.6	81.7
Absolute reduction (p-ppm)	22.2	38,360.3	58,995.3	87,360.1	88,638.1	92,151.7
Private Costs (000's)						
Fixed	$ 75.0	$ 122.5	$ 99.9	$ 1,759.2	$ 1,779.7	$ 1,773.7
Variable	109.0	3,866.1	10,867.7	14,633.9	14,792.6	26,918.8
Process change	-5.1	17.5	2,810.0	1,132.8	1,397.1	8,267.3
Waste treatment	189.1	230.9	181.5	7,796.5	7,796.5	7,796.5
Fuel substitution	0.0	3,740.2	7,976.1	7,463.8	7,378.7	12,628.7
Total private cost	184.0	3,988.6	10,967.6	16,393.1	16,572.3	28,692.5
Particulate Emissions						
Percent reduction	21.5	23.4	28.4	29.6	29.7	29.7
Absolute reduction (gms/sec)	2,967.6	3,222.8	3,917.9	4,078.1	4,085.2	4,087.3

EXHIBIT III-20

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 40.0 PERCENT

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(0%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	32.1	49.7	77.0	79.5	83.3
Absolute reduction (gms/sec)	0.9	2,346.4	3,637.2	5,632.8	5,817.1	6,097.6
SO_2 Exposures						
Percent reduction	0.0	34.0	52.3	77.5	78.6	81.7
Absolute reduction (p-ppm)	22.2	38,360.3	58,995.3	87,360.1	88,638.1	92,151.7
Private Costs (000's)						
Fixed	$ 191.8	$ 221.8	$ 213.1	$ 1,872.4	$ 1,892.9	$ 1,886.9
Variable	994.7	4,767.7	11,743.0	15,509.2	15,667.9	27,794.1
Process change	-5.1	17.5	2,810.0	1,132.8	1,397.1	8,267.3
Waste treatment	1,191.6	1,231.8	1,170.0	8,785.0	8,785.0	8,785.0
Fuel substitution	0.0	3,740.2	7,976.1	7,463.8	7,378.7	12,628.7
Total private cost	1,186.5	4,989.5	11,956.1	17,381.6	17,560.8	29,681.0
Particulate Emissions						
Percent reduction	65.1	66.4	71.1	72.2	72.3	72.3
Absolute reduction (gms/sec)	8,967.9	9,144.4	9,792.9	9,953.2	9,960.3	9,962.3

EXHIBIT III-21

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 60.0 PERCENT

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(0%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	32.1	49.7	77.0	79.5	83.3
Absolute reduction (gms/sec)	0.9	2,346.4	3,637.2	5,632.8	5,817.1	6,097.6
SO_2 Exposures						
Percent reduction	0.0	34.0	52.3	77.5	78.6	81.7
Absolute reduction (p-ppm)	22.2	38,360.3	58,995.3	87,360.1	88,638.1	92,151.7
Private Costs (000's)						
Fixed	$ 191.8	$ 221.8	$ 213.1	$ 1,872.4	$ 1,892.9	$ 1,886.9
Variable	994.7	4,767.7	11,743.0	15,509.2	15,667.9	27,794.1
Process change	-5.1	17.5	2,810.0	1,132.8	1,397.1	8,267.3
Waste treatment	1,911.6	1,231.8	1,170.0	8,785.0	8,785.0	8,785.0
Fuel substitution	0.0	3,740.2	7,976.1	7,463.8	7,378.7	12,628.7
Total private cost	1,186.5	4,989.5	11,956.1	17,381.6	17,560.8	29,681.0
Particulate Emissions						
Percent reduction	65.1	66.4	71.1	72.2	72.3	72.3
Absolute reduction (gms/sec)	8,967.9	9,144.4	9,792.9	9,953.2	9,960.3	9,962.3

EXHIBIT III-22

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 80.0 PERCENT

Calulation Point	1	2	3	4	5	6
Reduction greater than (%)	(0%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	32.1	49.7	77.0	79.5	83.3
Absolute reduction (gms/sec)	0.9	2,346.4	3,637.2	5,632.8	5,817.1	6,097.6
SO_2 Exposures						
Percent reduction	0.0	34.0	52.3	77.5	78.6	61.7
Absolute reduction (p-ppm)	22.2	38,360.3	58,995.3	87,360.1	88,638.1	92,151.7
Private Costs (000's)						
Fixed	$ 294.4	$ 288.7	$ 280.0	$ 1,939.3	$ 1,959.8	$ 1,953.8
Variable	1,154.7	4,810.3	11,785.6	15,551.8	15,710.5	27,836.7
Process change	-5.1	17.5	2,810.0	1,132.8	1,397.1	8,267.3
Waste treatment	1,454.2	1,341.3	1,279.5	8,894.5	8,894.5	8,894.5
Fuel substitution	0.0	3,740.2	7,976.1	7,463.8	7,378.7	12,628.7
Total private cost	1,449.1	5,099.0	12,065.6	17,491.1	17,670.3	29,790.5
Particulate Emissions						
Percent reduction	84.7	80.2	84.9	86.0	86.1	86.1
Absolute reduction (gms/sec)	11,662.6	11,044.7	11,693.2	11,853.5	11,860.5	11,862.6

EXHIBIT III-23

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 94.0 PERCENT

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(0%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	2.6	33.4	50.0	77.0	79.5	83.3
Absolute reduction (gms/sec)	193.0	2,441.0	3,660.9	5,632.8	5,817.1	6,097.6
SO_2 Exposures						
Percent reduction	2.2	36.0	52.6	77.5	78.6	81.7
Absolute reduction (p-ppm)	2,472.2	40,564.5	59,320.2	87,360.1	88,638.1	92,151.7
Private Costs (000's)						
Fixed	$ 675.7	$ 695.1	$ 508.5	$ 2,074.2	$ 2,094.7	$ 2,088.7
Variable	2,278.8	6,016.7	12,249.0	15,773.9	15,932.6	28,058.8
Process change	2.7	17.5	2,810.0	1,132.8	1,397.1	8,267.3
Waste treatment	2,299.3	2,323.1	1,836.4	9,251.5	9,251.5	9,251.5
Fuel substitution	652.5	4,371.2	8,111.1	7,463.8	7,378.7	12,628.7
Total private cost	2,954.5	6,711.8	12,757.5	17,848.1	18,027.3	30,147.5
Particulate Emissions						
Percent reduction	94.1	94.2	94.1	94.4	94.4	94.5
Absolute reduction (gms/sec)	12,957.6	12,975.6	12,958.6	13,004.3	13,011.3	13,013.4

EXHIBIT III-24

AGGREGATE LEAST COST CURVE FOR REDUCTION OF SO_2 EMISSIONS INCENTIVE NO.1

Calulation Point	1	2	3	4	5	6
Reduction greater than (%)	(10%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	20.3	48.8	61.2	81.6	83.3
Absolute reduction (gms/sec)	0.9	1,483.0	3,570.1	4,478.2	5,969.0	6,097.6
SO_2 Exposures						
Percent reduction	0.0	15.5	41.4	55.6	79.6	81.7
Absolute reduction (p-ppm)	22.2	17,453.1	46,691.9	62,656.8	89,734.2	92,151.7
Private Costs (000's)						
Fixed	$ 15.9	$ 42.5	$ 866.0	$ 1,700.5	$ 1,731.3	$ 1,726.2
Variable	-21.0	1,562.2	6,169.1	8,104.9	20,897.6	26,810.3
Process change	-5.1	-2.1	1.9	556.9	7,608.4	8,267.3
Waste treatment	0.0	63.3	3,844.2	7,640.5	7,640.5	7,640.5
Fuel substitution	0.0	1,543.5	3,189.0	1,608.0	7,380.0	12,628.7
Total private cost	-5.1	1,604.7	7,035.1	9,805.4	22,628.9	28,536.5
Unit Private Cost of Reducing						
SO_2 emissions ($x1000/cm/sec)	-5.775	1.082	1.971	2.190	3.791	4.680
SO_2 exposure ($x1000/p-ppm)	-0.230	0.092	0.151	0.156	0.252	0.310
Marginal Private Cost of Reducing						
SO_2 emissions ($x1000/gm/sec)		1.086	2.602	3.051	8.602	45.920
SO_2 exposure ($x1000/p-ppm)		0.092	0.186	0.174	0.474	2.444
Bonus Reduction in Particulate						
Percent reduction	0.1	0.5	3.5	9.5	11.0	11.0
Absolute reduction (gms/sec)	12.8	75.0	475.6	1,310.2	1,521.4	1,521.9

EXHIBIT III-25

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 20.0 PERCENT

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(10%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	20.3	48.8	61.2	81.6	83.3
Absolute reduction (gms/sec)	0.9	1,483.0	3,570.1	4,478.2	5,969.0	6,097.6
SO_2 Exposures						
Percent reduction	0.0	15.5	41.4	55.6	79.6	81.7
Absolute reduction (p-ppm)	22.2	17,453.1	46,691.9	62,656.8	89,734.2	92,151.7
Private Costs (000's)						
Fixed	$ 75.0	$ 123.1	$ 913.9	$ 1,748.4	$ 1,778.8	$ 1,773.7
Variable	109.0	1,687.0	6,278.0	8,213.8	21,006.1	26,918.8
Process change	-5.1	-2.1	1.9	556.9	7,608.4	8,267.3
Waste treatment	189.1	268.7	4,001.0	7,797.3	7,796.5	7,796.5
Fuel substitution	0.0	1,543.5	3,189.0	1,608.0	7,380.0	12,628.7
Total private cost	184.0	1,810.1	7,191.9	9,962.2	22,784.9	28,692.5
Particulate Emissions						
Percent reduction	21.5	23.3	22.2	28.2	29.7	29.7
Absolute reduction (gms/sec)	2,967.6	3,214.8	3,053.9	3,888.4	4,086.6	4,087.3

EXHIBIT III-26

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 40.0 PERCENT

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(10%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	20.3	48.8	61.2	81.6	83.3
Absolute reduction (gms/sec)	0.9	1,483.0	3,570.1	4,478.2	5,969.0	6,097.6
SO_2 Exposures						
Percent reduction	0.0	15.5	41.4	55.6	79.6	81.7
Absolute reduction (p-ppm)	22.2	17,453.1	46,691.9	62,656.8	89,734.2	92,151.7
Private Costs (000's)						
Fixed	$ 191.8	$ 222.4	$ 1,045.9	$ 1,861.6	$ 1,892.0	1,886.9
Variable	994.7	2,588.6	7,195.5	9,089.1	21,881.4	27,794.1
Process change	-5.1	-2.1	1.9	556.9	7,608.4	8,267.3
Waste treatment	1,191.6	1,269.6	5,050.5	8,785.8	8,785.0	8,785.0
Fuel substitution	0.0	1,543.5	3,189.0	1,608.0	7,380.0	12,628.7
Total private cost	1,186.5	2,811.0	8,241.4	10,950.7	23,773.4	29,681.0
Particulate Emissions						
Percent reduction	65.1	66.3	69.2	70.9	72.3	72.3
Absolute reduction (gms/sec)	8,967.9	9,136.5	9,537.1	9,763.5	9,961.9	9,962.3

EXHIBIT III-27

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 60.0 PERCENT

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(10%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	20.3	48.8	61.2	81.6	83.3
Absolute reduction (gms/sec)	0.9	1,483.0	3,570.1	4,478.2	5,969.0	6,097.6
SO_2 Exposures						
Percent reduction	0.0	15.5	41.4	55.6	79.6	81.7
Absolute reduction (p-ppm)	22.2	17,453.1	46,691.9	62,656.8	89,734.2	92,151.7
Private Costs (000's)						
Fixed	$ 191.8	$ 222.4	$ 1,045.9	$ 1,861.6	$ 1,892.0	$ 1,886.9
Variable	994.7	2,588.6	7,195.5	9,089.1	21,881.4	27,794.1
Process change	-5.1	-2.1	1.9	556.9	7,608.4	8,267.3
Waste treatment	1,191.6	1,269.6	5,050.5	8,785.8	8,785.0	8,785.0
Fuel substitution	0.0	1,543.5	3,189.0	1,608.0	7,380.0	12,628.7
Total private cost	1,186.5	2,811.0	8,241.4	10,950.7	23,773.4	29,681.0
Particulate Emissions						
Percent reduction	65.1	66.3	69.2	70.9	72.3	72.3
Absolute reduction (gms/sec)	8,967.9	9,136.5	9,537.1	9,763.5	9,961.9	9,962.3

EXHIBIT III-28

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 80.0 PERCENT

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(10%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	20.3	48.8	61.2	81.6	83.3
Absolute reduction (gms/sec)	0.9	1,483.0	3,570.1	4,478.2	5,969.0	6,097.6
SO_2 Exposures						
Percent reduction	0.0	15.5	41.4	55.6	79.6	81.7
Absolute reduction (p-ppm)	22.2	17,453.1	46,691.9	62,656.8	89,734.2	92,151.7
Private Costs (000's)						
Fixed	$ 294.4	$ 289.3	$ 1,112.8	$ 1,928.5	$ 1,958.9	$ 1,953.8
Variable	1,154.7	2,631.2	7,238.1	9,131.7	21,924.0	27,836.7
Process change	-5.1	-2.1	1.9	556.9	7,608.4	8,267.3
Waste treatment	1,454.2	1,379.1	5,160.0	8,895.3	8,894.5	8,894.5
Fuel substitution	0.0	1,543.5	3,189.0	1,608.0	7,380.0	12,628.7
Total private cost	1,449.1	2,920.5	8,350.9	11,060.2	23,882.9	29,790.5
Particulate Emissions						
Percent reduction	84.7	80.1	83.0	84.7	86.1	86.1
Absolute reduction (gms/sec)	11,662.6	11,036.7	11,437.4	11,663.8	11,862.2	11,862.6

64

EXHIBIT III-29

AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION OF 94.0 PERCENT

Calculation Point Reduction greater than (%)	1 (10%)	2 (20%)	3 (40%)	4 (60%)	5 (80%)	6 (Maximum)
SO_2 Emissions						
Percent reduction	2.6	21.6	50.1	61.9	81.6	83.3
Absolute reduction (gms/sec)	193.0	1,578.6	3,665.8	4,526.5	5,969.0	6,097.6
SO_2 Exposures						
Percent reduction	2.2	16.5	42.4	56.1	79.6	81.7
Absolute reduction (p-ppm)	2,472.2	18,568.6	47,807.4	63,317.2	89,734.2	92,151.7
Private Costs (000's)						
Fixed	$ 675.7	$ 695.7	$ 1,376.4	$ 2,157.3	$ 2,093.8	$ 2,088.7
Variable	2,278.8	3,888.9	8,270.1	9,805.6	22,146.1	28,058.8
Process change	2.7	-2.1	1.9	556.9	7,608.4	8,267.3
Waste treatment	2,299.3	2,360.9	5,773.3	9,453.1	9,251.5	9,251.5
Fuel substitution	652.5	2,225.8	3,871.3	1,952.9	7,380.0	12,628.7
Total private cost	2,954.5	4,584.6	9,646.5	11,942.9	24,239.9	30,147.5
Particulate Emissions						
Percent reduction	94.1	94.1	94.2	94.1	94.5	94.5
Absolute reduction (gms/sec)	12,957.6	12,968.9	12,974.8	12,958.3	13,013.0	13,013.4

EXHIBIT III-30

COMPARISON OF COST OF EQUIPROPORTIONAL AND LEAST COST STRATEGIES

	EP	LC
SO_2 and SP Reduction		
80%	$29,790,500	$23,882,900
Maximum	$30,147,500	$30,147,500
Reduction of Human Exposure to SO_2 and Particulate		
80%	$29,790,500	$21,708,200
Maximum	$30,147,500	$28,536,500
SO_2 Concentration Reduction to less than		
0.060 ppm	$10,811,600	$10,615,000
0.040 ppm		$11,216,000
0.020 ppm	$28,536,500	$20,965,000

(2) Reduce human exposure by at least 20, 40, 60, 80, and maximum percent.

As explained in Chapter II, the human exposure in a subarea of a city may be defined as the product of the population of the subarea times the average annual concentration. If the model city is divided into such subareas, then the total human exposure, E, in the city is simply the sum of the subarea exposures. That is,

$$E = C_iP_i + C_2P_2 + . . . C_nP_n$$

where C_i denotes the average annual SO_2 concentration in the ith subarea and P_i denotes the total population of the ith subarea.

- Equiproportional strategy: Since the reduction of each source's emissions by the same percentage will produce a reduction in the total concentration by the same percentage, and thus the same percentage reduction in human exposure, the EP strategy is the same as the strategy for reducing SO_2 emissions by that percentage reduction. Thus, the EP strategy solution for reducing human exposure is again that given in Exhibits III-18 through III-23.

- Least cost strategy: Exhibit III-31 shows the costs associated with each level of reduction and the emissions of SO_2 and particulate for each level. The aggregate least cost for reduction of human exposure to SO_2 under the nine different incentive schemes is shown in Exhibit III-22.

- Difference in cost of the EP and LC strategies: Comparing the costs of reducing human exposure for the two strategies in Exhibit III-30 shows that the EP strategy cost $8,082,300 more than the LC strategy to reduce human exposure to both SO_2 and particulate by 80 percent and $11,611,000 more to reduce SO_2 and particulate the maximum possible. Illustrating the case when the objective is to reduce human exposure to calculation point 4 under incentive scheme no. 4, Exhibit III-32 shows for each source the dollars per measure output for the least cost and equiproportional strategies for reducing SO_x. Exhibit III-33 and Exhibit III-34 give for the same example the estimated total annual cost and the fixed and variable cost for each source under the equiproportional and least cost strategies, respectively.

(3) Reduce concentration to less than 0.060, 0.040, and 0.020 ppm

- Equiproportional strategy: The highest concentration occurs at 0.122 ppm. From this concentration to reduce the concentration to less than 0.060, 0.040, and 0.020 ppm by the equiproportional strategy would require a 50.8, 67.2, and 83.6 percent reduction, respectively, in the emissions by each source. Again, the EP strategy for reducing concentrations below a certain level has the same solution and costs as the strategy for reducing SO_2 emissions and can be read from Exhibits III-18 through III-23 for the above percentages.

- Least cost strategy: Exhibit III-35 shows the least cost solution to reducing all concentrations within the model city to 0.060, 0.040, 0.020 ppm. Exhibit III-36 gives the individual emissions reduction requirements for each source on the least cost curve for reduction of SO_2 emissions.

- Difference in cost in EP and LC strategies: Exhibit III-30 shows that there is a difference of $196,000 and $77,599,000 in the cost of the EP and LC strategies for reducing concentrations at all receptor points to less than 0.060 and 0.020 ppm, respectively.

66

EXHIBIT III-31

AGGREGATE LEAST COST CURVE FOR REDUCTION OF HUMAN EXPOSURE TO SO_2
INCENTIVE NO. 1

Calculation Point	1	2	3	4	5	6
Reduction greater than (%)	(10%)	(20%)	(40%)	(60%)	(80%)	(Maximum)
SO_2 Emissions						
Percent reduction	0.0	15.0	35.9	49.7	81.2	83.3
Absolute reduction (gms/sec)	0.9	1,099.0	2,627.1	3,637.6	5,943.4	6,097.6
SO_2 Exposures						
Percent reduction	0.0	20.3	43.1	61.3	80.7	81.7
Absolute reduction (p-ppm)	22.2	22,880.5	45,635.4	69,086.9	91,035.9	92,151.7
Private Costs (000's)						
Fixed	$15.9	$ 42.5	$ 42.5	$ 877.0	$ 1,732.2	$ 1,726.2
Variable	-21.0	1,596.6	6,090.9	7,557.7	19,976.0	26,810.3
Process change	-5.1	1.9	1.9	1.9	1,439.0	8,267.3
Waste treatment	0.0	63.3	63.3	3,869.6	7,640.5	7,640.5
Fuel substitution	0.0	1,573.9	6,068.2	5,573.2	12,628.7	12,628.7
Total private cost	-5.1	1,639.1	6,133.4	8,454.7	21,708.2	28,536.5
Unit Private Cost of Reducing						
SO_2 emissions (\$X1000/gm/sec)	-5.775	1.491	2.335	2.319	3.652	4.680
SO_2 exposure (\$X1000/p-ppm)	-0.230	0.072	0.126	0.122	0.238	0.310
Marginal Prvt. Cost of Reducing						
SO_2 emissions (\$X1000/gm/sec)	1.497	2.941	2.277	5.757	44.276	
SO_2 exposure (\$X1000/p-ppm)	0.072	0.175	0.113	0.605	6.120	
Bonus Reduction in Particulate Emissions						
Percent reduction	0.1	0.3	0.5	1.0	11.0	11.0
Absolute reduction (gms/sec)	12.8	38.8	71.9	138.7	1,519.5	1,521.9

EXHIBIT III-32

COMPARISON OF COST PER MEASURE OF OUTPUT: LEAST COST AND EQUIPROPORTIONAL STRATEGIES FOR REDUCING HUMAN EXPOSURE (PEOPLE-PPM) TO SO_2

	LC	EP	PRIVATE COST ONLY
INCENTIVE	4	4	
CALCULATION PT	4	4	
PERCENT REDUC.	61.3	77.5	

Source Number	Source	Measure of Output	Cost per Measure of Output		
			LC	EP	Differ.
		10^9 Kwh			
1	Power plant 1	4.9	$ 90,000	$704,388	$(614,388)
2	Power plant 2	4.2	824,405	824,405	-0-
3	Power plant 3	2.0	55,500	527,250	471,750
	Stationary combustion	10^9 Btu			
	Industrial				
5	Coal	50	10	110	100
6	Coal	100	10	102	92
7	Coal	300	10	96	86
8	Residual oil	400	20	100	80
	Multiple-family				
9	Residual oil	10	130	130	-0-
10	Residual oil	50	126	126	-0-
	Commercial				
11	Coal	200	(22.5)	18	(4.5)
12	Residual oil	300	75	125	50
13-32	Area sources	10^{12} Btu			
	Coal	6.6	40,212	169,136	128,924
	Residual oil	54.5	68,132	114,906	46,774
		Value added			
35	Nonferrous foundry	$ 855,000	-0-	0.0026	(0.0026)
37	Petroleum refining	4,573,000	0.0031	0.0031	-0-
38	Sulfuric acid manufacture	1,699,000	0.0228	0.0228	-0-

68

EXHIBIT III-33

ESTIMATED ANNUAL COSTS OF REDUCING HUMAN EXPOSURE (PEOPLE-PPM) TO SO_2

STRATEGY	EP	PRIVATE COSTS ONLY
INCENTIVE	4	
CALCULATION PT.	4	
PERCENT REDUC.	77.5	

Source Number	Source	Measure of Output	Estimated Annual Cost (000's)			Cost per Measure of Output
			Fixed	Variable	Total	
		10^9 Kwh				
1	Power plant 1	4.9	$ 494.1	$ 2,957.4	$ 3,451.5	$704,388
2	Power plant 2	4.2	500.7	2,961.8	3,462.5	824,405
3	Power plant 3	2.0	-0-	1,054.5	1,054.5	527,250
	Stationary combustion	10^9 Btu				
	Industrial					
5	Coal	50	1.2	4.3	5.5	110
6	Coal	100	1.7	8.5	10.2	102
7	Coal	300	3.4	25.5	28.9	96
8	Residual oil	400	-0-	40.0	40.0	100
	Multiple-family					
9	Residual oil	10	-0-	1.3	1.3	130
10	Residual oil	50	-0-	6.3	6.3	126
	Commercial					
11	Coal	200	9.5	(6.0)	3.5	18
12	Residual oil	300	-0-	37.5	37.5	125
13-32	Area sources	10^{12} Btu				
	Coal	6.6	-0-	1,116.3	1,116.3	169,136
	Residual oil	54.5	-0-	6,262.4	6,262.4	114,906
		Value added				
35	Nonferrous foundry	$ 855,000	0.4	18.9	19.3	0.0226
37	Petroleum refining	4,573,000	14.0	-0-	14.0	0.0031
38	Sulfuric acid manufacture	1,699,000	2.0	36.7	38.7	0.0228
	TOTAL		1,027.0	14,525.4	15,552.4	

EXHIBIT III-34

ESTIMATED ANNUAL COSTS OF REDUCING HUMAN EXPOSURE (PEOPLE-PPM) TO SO_2

STRATEGY	LC PRIVATE COSTS ONLY
INCENTIVE	4
CALCULATION PT.	4
PERCENT REDUC.	61.3

Source Number	Source	Measure of Output	Estimated Annual Cost (000's)			Cost per Measure of Output
			Fixed	Variable	Total	
		10^9 Kwh				
1	Power plant 1	4.9	$ -0-	$ 441.0	$ 441.0	$ 90,000
2	Power plant 2	4.2	500.7	2,961.8	3,462.5	824,405
3	Power plant 3	2.0	-0-	111.0	111.0	55,500
	Stationary combustion	10^9 Btu				
	Industrial					
5	Coal	50	-0-	.5	.5	10
6	Coal	100	-0-	1.0	1.0	10
7	Coal	300	-0-	3.0	3.0	10
8	Residual oil	400	-0-	8.0	8.0	20
	Multiple-family					
9	Residual oil	10	-0-	1.3	1.3	130
10	Residual oil	50	-0-	6.3	6.3	126
	Commercial					
11	Coal	200	-0-	(14.0)	(4.5)	(22.5)
12	Residual oil	300	-0-	22.5	22.5	75
13-32	Area sources	10^{12} Btu				
	Coal	6.6	9.5	265.4	265.4	40,212
	Residual oil	54.5	-0-	3,713.2	3,713.2	68,132
		Value added				
35	Nonferrous foundry	$ N/A				-0-
37	Petroleum refining	4,573,000	14.0	-0-	14.0	0.0031
38	Sulfuric acid manufacture	1,699,000	2.0	36.7	38.7	0.0228
	TOTAL		526.2	7,557.7	8,083.9	

EXHIBIT III-35

AGGREGATE LEAST COST CURVE FOR REDUCTION OF SO_2 CONCENTRATION (TAX INCENTIVE NO. 9)

Calculation Point	1	2	3
SO_2 Concentration Objective (ppm)	0.060	0.040	0.020
SO_2 Emissions			
Percent reduction	61.72	64.24	80.41
Absolute reduction (gms/sec)	4,516.2	4,700.3	5,883.9
SO_2 Exposures			
Percent reduction	51.69	61.62	79.55
Absolute reduction (p-ppm)	58,298.0	69,500.3	89,721.2
Total Private Cost ($X1000)	10,615.0	11,216.0	20,965.0

71

EXHIBIT III-36

INDIVIDUAL EMISSION REDUCTION REQUIREMENT AT EACH POINT ON THE AGGREGATE LEAST COST CURVE FOR REDUCTION OF SO_2 CONCENTRATIONS

(REQUIREMENT EXPRESSED AS PERCENT OF TOTAL SO_2 EMISSIONS OF EACH SOURCE)

Source Number	Source Name	Computation Point		
		1 (0.060 ppm)	2 (0.040 ppm)	3 (0.020 ppm)
1	Power plant 1	90.00%	76.36%	92.92%
2	Power plant 2	74.71	90.00	93.38
3	Power plant 3	99.90	99.90	99.90
4	Power plant 4	0.00	0.00	0.00
5	I Stat. comb. coal	81.10	81.10	99.90
6	I Stat. comb. coal	81.10	81.10	99.90
7	I Stat. comb. coal	81.10	81.10	99.90
8	I Stat. comb. resid.	98.90	98.90	98.90
9	MF Stat. comb. resid.	38.40	58.30	98.90
10	MF Stat. comb. resid.	0.00	38.40	78.90
11	C Stat. comb. coal	10.50	44.80	99.90
12	C Stat. comb. resid.	38.05	38.40	98.90
13	Ind. area 1 coal	25.00	25.00	75.00
14	Ind. area 1 resid.	78.90	38.40	78.90
15	Ind. area 2 coal	75.00	75.00	75.00
16	Ind. area 2 resid.	78.90	78.90	78.90
17	Ind. area 3 coal	0.00	0.00	75.00
18	Ind. area 3 resid.	0.00	0.00	78.90
19	Ind. area 4 coal	25.00	25.00	25.00
20	Ind. area 4 resid.	38.40	38.40	70.30
21	MF area 18 resid.	38.40	78.90	78.90
22	MF area 19 resid.	38.40	56.48	78.90
23	MF area 20 resid.	38.40	38.40	78.90
24	MF area 22 resid.	38.40	58.30	78.90
25	MF area 26 resid.	38.40	38.40	78.90
26	Com. area 23 coal	0.00	50.00	75.00
27	Com. area 23 resid.	38.40	59.09	78.90

Exhibit III-36, cont'd

Source Number	Source Name	Computation Point 1 (0.060 ppm)	 2 (0.040 ppm)	 3 (0.020 ppm)
28	Com. area 24 coal	0.00%	0.00%	77.00%
29	Com. area 24 resid.	0.00	38.40	78.90
30	Com. area 27 coal	0.00	50.00	75.00
31	Com. area 27 resid.	38.40	55.03	78.90
32	Com. area 28 resid.	28.78	49.59	78.90
33	Concrete batch	0.00	0.00	0.00
34	Ferrous foundry	0.00	0.00	0.00
35	Non-ferrous found.	0.00	0.00	8.70
36	Pet. ref. cat. crack	0.00	0.00	0.00
37	Pet. ref. sulf. rec.	95.00	95.00	95.00
38	Sulfuric acid	75.00	75.00	75.00
39	Iron-steel sint. pt.	0.00	0.00	0.00
40	Iron-steel bst. fur.	0.00	0.00	0.00
41	Iron-steel open ht.	0.00	0.00	0.00
42	Iron-steel oxl. oht.	0.00	0.00	0.00
43	Iron-steel bsc. ox.	0.00	0.00	0.00
44	Iron-steel elec. ac.	0.00	0.00	0.00
45	Kraft mill. rec. fur.	0.00	0.00	0.00
46	Kraft mill. lime kn.	0.00	0.00	0.00
47	Municipal inciner.	0.00	0.00	0.00

IV. NATIONAL CAPITAL AREA STUDY

This study was funded by NAPCA Contract No. PH 86-68-37 to develop estimates of the cost of achieving selected air quality levels in the National Capital Area* under different air pollution abatement strategies. Our report, "A Cost-Effectiveness Study of Air Pollution Abatement in the National Capital Area" (January 1969), summarizes the methods and results of that study.

OBJECTIVES

This study had two principal objectives:

(1) To compare the total annual cost of three stipulated abatement strategies for achieving certain air quality levels in the National Capital Area

(2) To compare the cost of abatement to various classes of emission sources under the three strategies. The three strategies studied are:

a. The least cost combination of emission controls which achieves selected air quality levels, "least cost" measuring the least total cost for the whole National Capital Area

b. Restricting fossil fuels to 1 percent sulfur by weight or less

c. "Universal abatement," by which all sources simultaneously take successively greater steps in reducing pollutant emissions until all applicable control alternatives stipulated for each source have been employed to achieve the maximum reduction possible

The pollutants that were analyzed for abatement cost in this study were sulfur oxides (SO_x) and suspended particulates (SP). The air quality levels selected as a basis for cost effectiveness analysis to achieve the first objective were provided by the Public Health Service. Exhibit IV-1 shows the air quality levels considered for sulfur oxides and particulates.

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* District of Columbia; Montgomery and Prince George's Counties in Maryland; Arlington, Fairfax, Loudon, and Prince William Counties in Virginia; Cities of Alexandria and Falls Church, Virginia.

EXHIBIT IV-1

AIR QUALITY LEVELS PROPOSED FOR COST ANALYSIS[a]

Sulfur Oxides (ppm)	Suspended Particulate ($\mu gms/m^3$)
0.015	55.0
0.025	65.0
0.035	75.0

[a] Public Health Service.

To attain objective (2) in comparing the cost of abatement to various classes of emission sources, estimated annual costs were determined for each of the 99 major sources in the Area and for 13 aggregates of small sources.

Major sources are called point sources and are defined as individual sites that emit more than 100 tons a year of a single pollutant. The several thousand small sources were apportioned into 13 aggregations on a fuel use basis by census tract using a coordinate location grid. These apportioned sources are called area sources.

A computer-assisted model was developed which simulates the average annual concentration of the two pollutants in the National Capital Area. Other programs then compute the estimated annual cost of simultaneously reducing ground-level concentrations of SO_x and SP to stated levels at a number of designated receptor points under each of three strategies for areawide abatement. Exhibit IV-2 gives a logic diagram of the method of analysis and computer programs used in this study and shows how the output of some programs forms the input to other programs. Flow diagrams and FORTRAN IV listings of the computer programs (except CAP) are given in Appendices A and D. The CAP program is the collective name given to the programs written for the Olivetti Programma desk top computer to semiautomate the formulas in Appendix C.

INPUTS

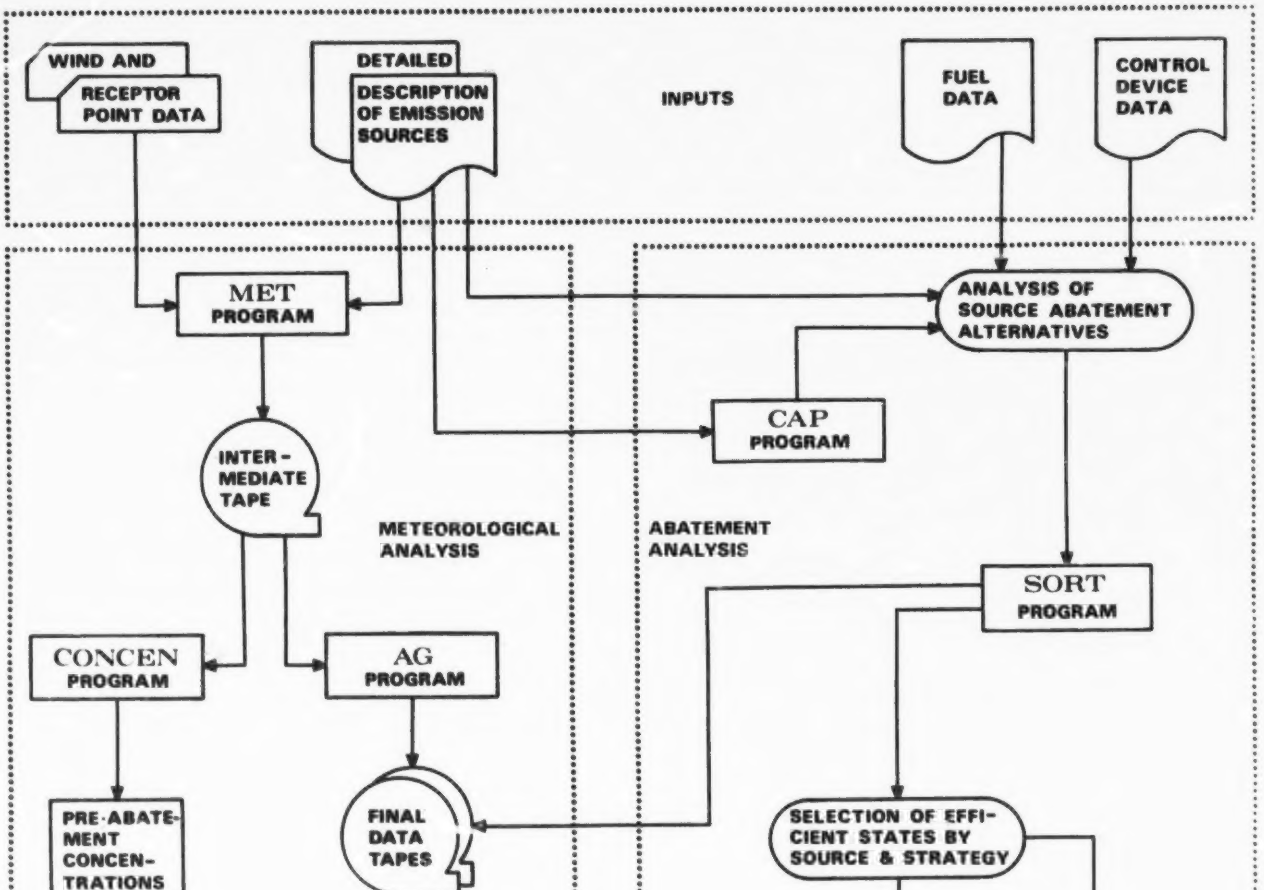
There are four types of inputs:

(1) Devices for SO_x and particulate emission control: their types, sizes, compatibility with sources, collection efficiencies, and capital, operating, and maintenance costs

(2) Cost, sulfur and ash content, heat content, and consumption of fuel oils (residual and distillate), coal (bituminous and anthracite), coke, and natural gas

EXHIBIT IV-2

ANALYTICAL FLOW DIAGRAM



WIND AND
RECEPTOR POINT DATA
DETAILED
DESCRIPTION OF EMISSION SOURCES
INPUTS
FUEL DATA
CONTROL DEVICE DATA
MET PROGRAM
ANALYSIS OF SOURCE ABATEMENT ALTERNATIVES
CAP PROGRAM
INTER-MEDIATE TAPE
METEOROLOGICAL ANALYSIS
ABATEMENT ANALYSIS
SORT PROGRAM
CONCEN PROGRAM
AG PROGRAM
PRE-ABATE-MENT CONCEN-TRATIONS
FINAL DATA TAPES
SELECTION OF EFFI-CIENT STATES BY SOURCE & STRATEGY
INT CODE PROGRAM
SORTCON PROGRAM
ANALYSIS OF RESULTS
FINAL ANALYSIS
FINAL REPORT

76

(3) Major characteristics of the point and area emission sources, including:

- grid location
- average annual emissions of SO_x and particulate
- fuel and heat requirements
- number and heights of smokestacks and emission points
- number and types of furnaces
- existing control devices
- rate of gaseous throughput
- hours of operation per year
- area source emissions broken down by the following fuel use or activity classes: anthracite coal, bituminous coal, distillate oil, residual oil, natural gas, gasoline, gasoline evaporation, diesel motor vehicles, diesel railroads, on-site incineration, backyard open burning, process losses, aircraft exhaust

(4) Receptor point grid locations, frequency distributions of wind vectors, and other required meteorological data

Exhibit IV-3 gives the classes of point and area emission sources of SO_x and particulate found in the National Capital Area and their percentage contribution to total emissions. These sources emit SO_x and particulate primarily from the combustion of fuels for space heating and power generation or from refuse incineration.

The locations of the point sources on the coordinate grid lines, which also form the area source boundaries, appear in Exhibit IV-4 as stars. Note the high density of point sources in the urban core area, for which a finer grid was used. The black dots are the 47 arbitrarily chosen receptor points at which ground level concentrations of pollutants were estimated by a meteorological diffusion model.

The study was limited to stationary emission sources within the National Capital Area. Emissions from mobile sources (auto, truck, railroad, aircraft) were treated as irreducible background concentration.

Meteorological Analysis

The meteorological computer model provided by the Public Health Service (see Appendix A) and used in the Model City I and Model City II studies determined the annual average concentration of SO_x and SP at each receptor point per unit emission from each source point.

Contributing sources of pollution outside the area were not taken into account. It should be noted that while particulate of various dimensions may be emitted from sources, only respirable particulate (i.e., suspended particulate, SP) is calculated at the receptor points. Suspended particulates are assumed to be less than ten microns and to constitute a constant 100 percent of the total particulate emitted by each point and area source.

EXHIBIT IV-3

ESTIMATED EMISSIONS SO_x AND PARTICULATE FROM POINT AND AREA SOURCES IN 1967 [a]

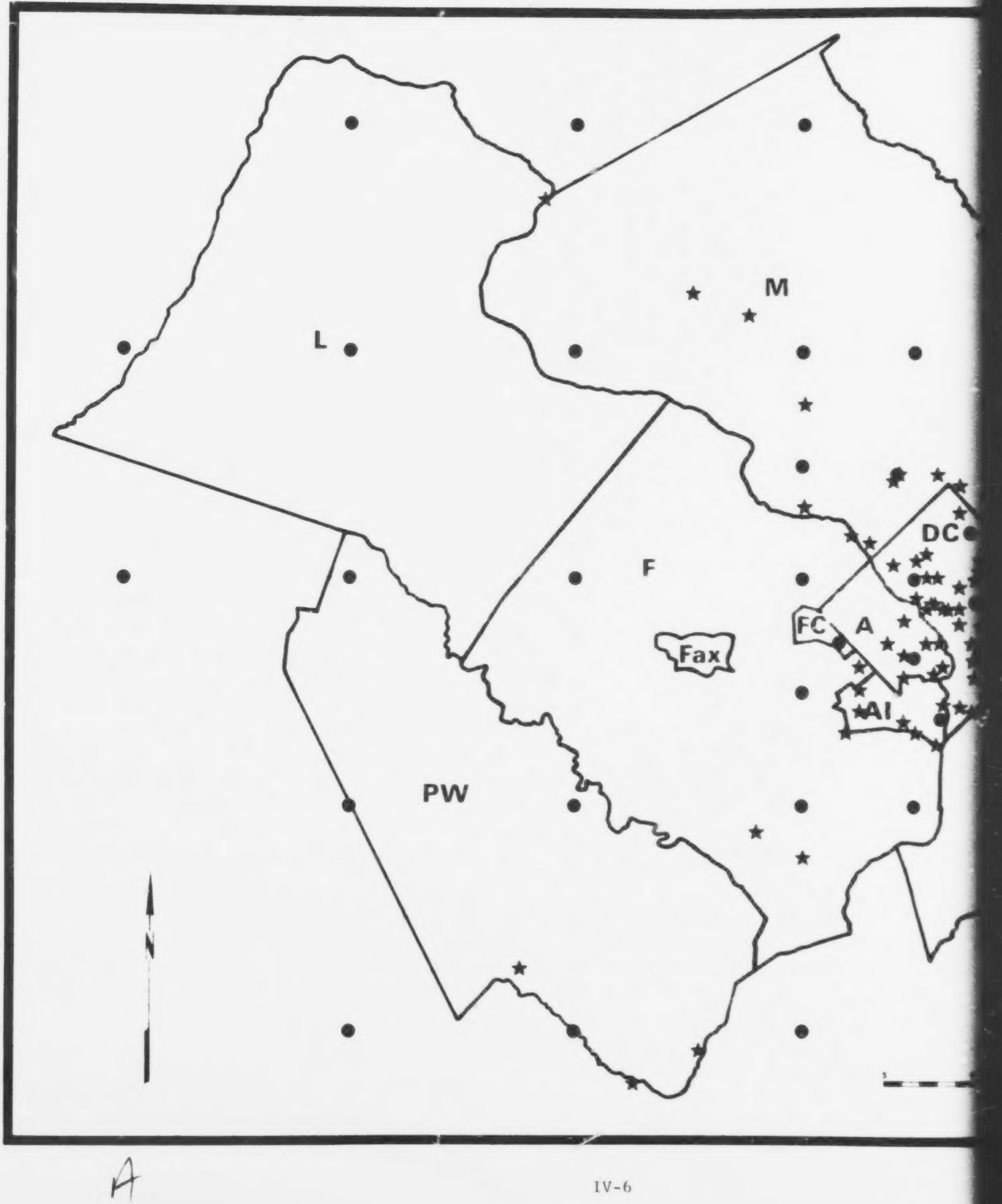
Emission Source Class	Emissions			
	SO_x		Particulate	
Point source classes [b]	Tons/yr.	%	Tons/yr.	%
Apartments	6,308	2.6	224	0.6
Commercial and local government	2,117	1.0	419	1.2
Federal Government	20,572	8.4	2,059	5.8
Hospital	2,566	1.0	212	0.6
Hotels	642	0.3	19	0.05
Municipal incinerators	645	0.3	1,739	5.0
Open burning dumps	96	0.04	3,745	10.6
Power plants	155,799	63.2	9,683	27.5
Universities	2,132	0.9	992	2.8
Process industries	35	0.01	645	1.8
Total point emissions	190,912	77.8	19,737	56.0
Aggregated area sources: [c]				
Coal users (anthr. & bitum.)	1,673	0.7	1,592	4.5
Oil users (distil. & resid.)	50,610	20.5	3,805	10.8
Natural gas users	-0-	-0-	774	2.2
On-site incineration	-0-	-0-	2,034	5.8
Backyard open burning	118	0.05	264	0.7
Process losses	-0-	-0-	365	1.0
Total stationary emissions	243,313	98.9	28,571	81.0
Mobile emissions (auto, truck, railroad, aircraft) [d]	3,381	1.4	6,672	18.9
Total emissions	246,694		35,243	

[a] Public Health Service.

[b] A "point source" emits more than 100 tons a year of a single pollutant.

[c] An "area source" is an aggregation of sources each of which emits less than 100 tons a year of a single pollutant.

[d] These are area sources for which no controls were stipulated.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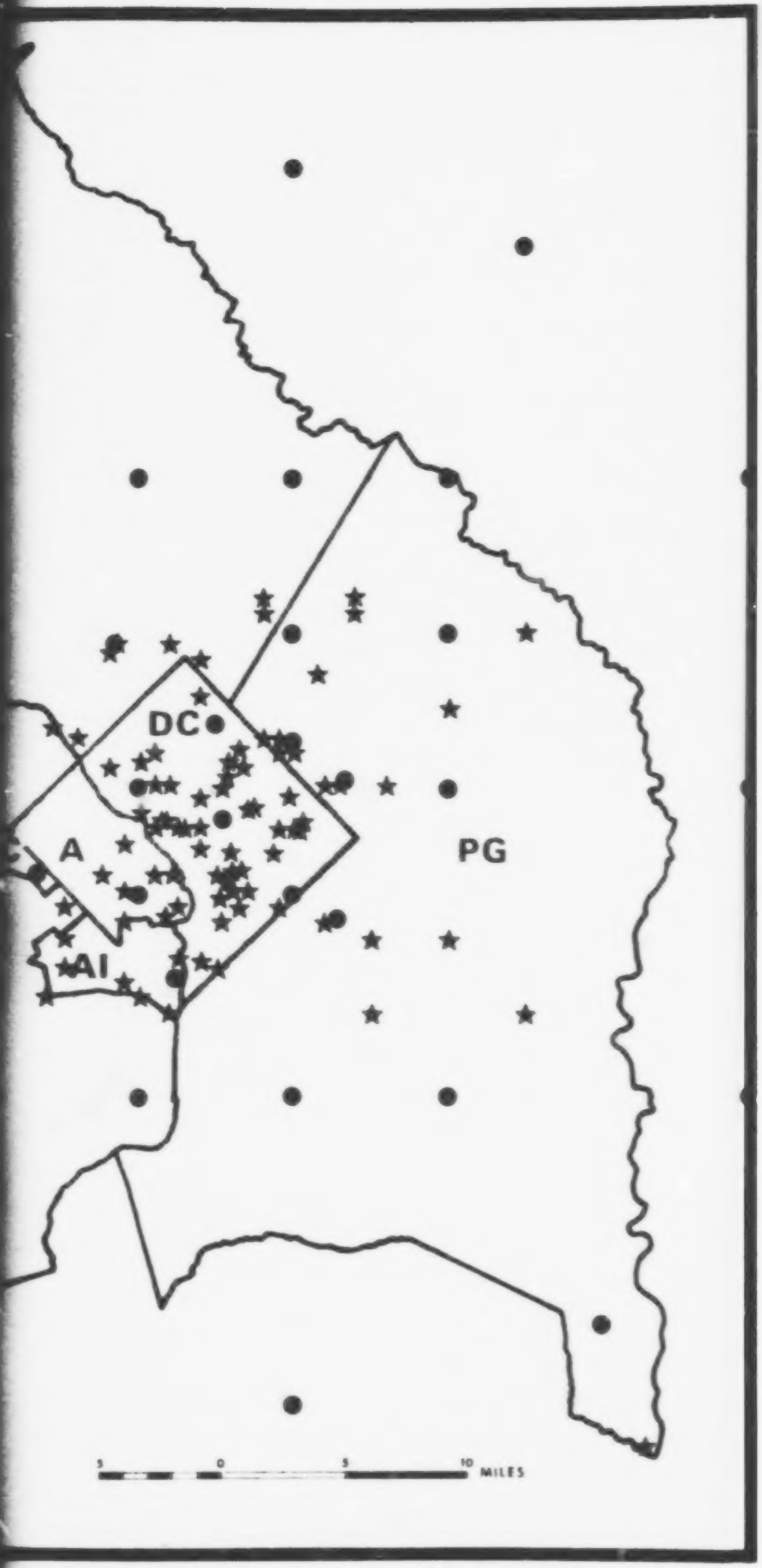

LEGEND

★	Emission Source
●	Receptor Point

NATIONAL CAPITAL AREA

A	Arlington County
Al	Alexandria
DC	District Of Columbia
F	Fairfax County
Fax	Fairfax
FC	Falls Church
L	Loudoun County
M	Montgomery County
PG	Prince Georges County
PW	Prince William County

EXHIBIT IV-4
MAJOR EMISSION SOURCES AND RECEPTOR POINTS

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Washington, D.C.

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From the output of the MET program the CONCEN (see Appendix D) program determines pre-abatement concentrations of SO_x and SP at the 47 receptor points (Exhibit IV-3). These pre-abatement concentrations were used to construct Exhibits IV-5 and IV-6, which show concentrations of SO_x and SP, respectively.

"Pre-abatement" means before simulation of the abatement strategies postulated for this study. The black contours, called iso-intensity lines, connect points of equal annual average (arithmetic mean) concentrations of sulfur oxides in parts per million (ppm). The iso-intensity lines were interpolated from the concentration at each receptor point. The estimated annual average concentrations of sulfur oxides shown by these iso-intensity lines range from negligible values to 0.06 ppm. The estimated SP concentrations are shown in Exhibit IV-6. These concentrations range from 50 micrograms per cubic meter ($\mu gms/m^3$), as an annual average, to 80 $\mu gms/m^3$. These predicted peak concentrations of SO_x and SP shown are closely corroborated by the annual average of the observations recorded at the Continuous Air Monitoring Program (CAMP) Site, at the same approximate location: 0.05 ppm for SO_x and 100 $\mu gms/m^3$ for SP.

The AG program (see Appendix D) also uses the MET output to aggregate the area sources by fuel use or activity class. These classes are then treated in the same way as point sources with respect to emission control alternatives and states.

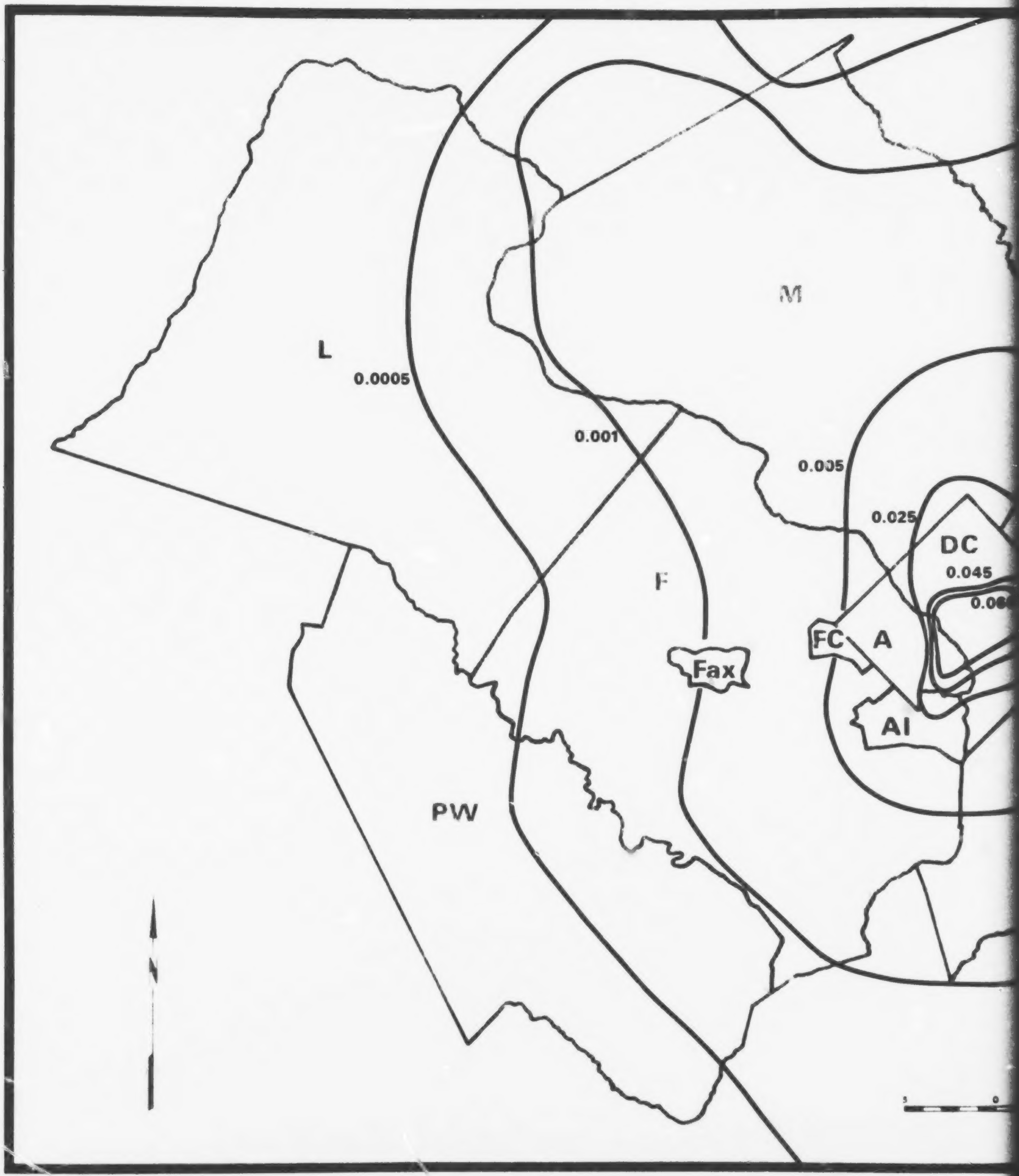
Abatement Analysis

The major part of the study effort is the analysis of emission control technologies. Analysis begins with a listing of the technologies assumed to be available to each source for controlling its emissions of SO_x and particulate, including changes in fuel and installation of compatible control devices. Computation was assisted in the study by the semi-automation of the formulas given in Appendix C for the Olivetti Programma desk top computer. These Olivetti programs are referred to collectively as the CAP program in Exhibit IV-2.

As in the model city studies discussed in Chapters II and III, the emission control technologies for stationary combustion and process sources included fuel substitution, fuel switching, and the installation of mechanical control equipment. For this study the mechanical control devices considered included mechanical collectors, electrostatic precipitators, wet scrubbers, and fabric filters.

Exhibit IV-7 shows the emission control technologies assumed to be practical and available to major (point) stationary combustion sources using coal or oil for the generation of heat or power. In addition, this study analyzed several methods for the control of refuse incineration, as follows:

Upgrading of Existing Facilities - Upgrading is applicable to both municipal and other (apartment, commercial, and industrial) incinerators. For municipal incinerators, upgrading includes installation of one or more types of particulate control equipment. This equipment consists of either a type of wet scrubbing device alone or in series with a cyclone collector of an electrostatic precipitator. The only pollutant controlled is particulate.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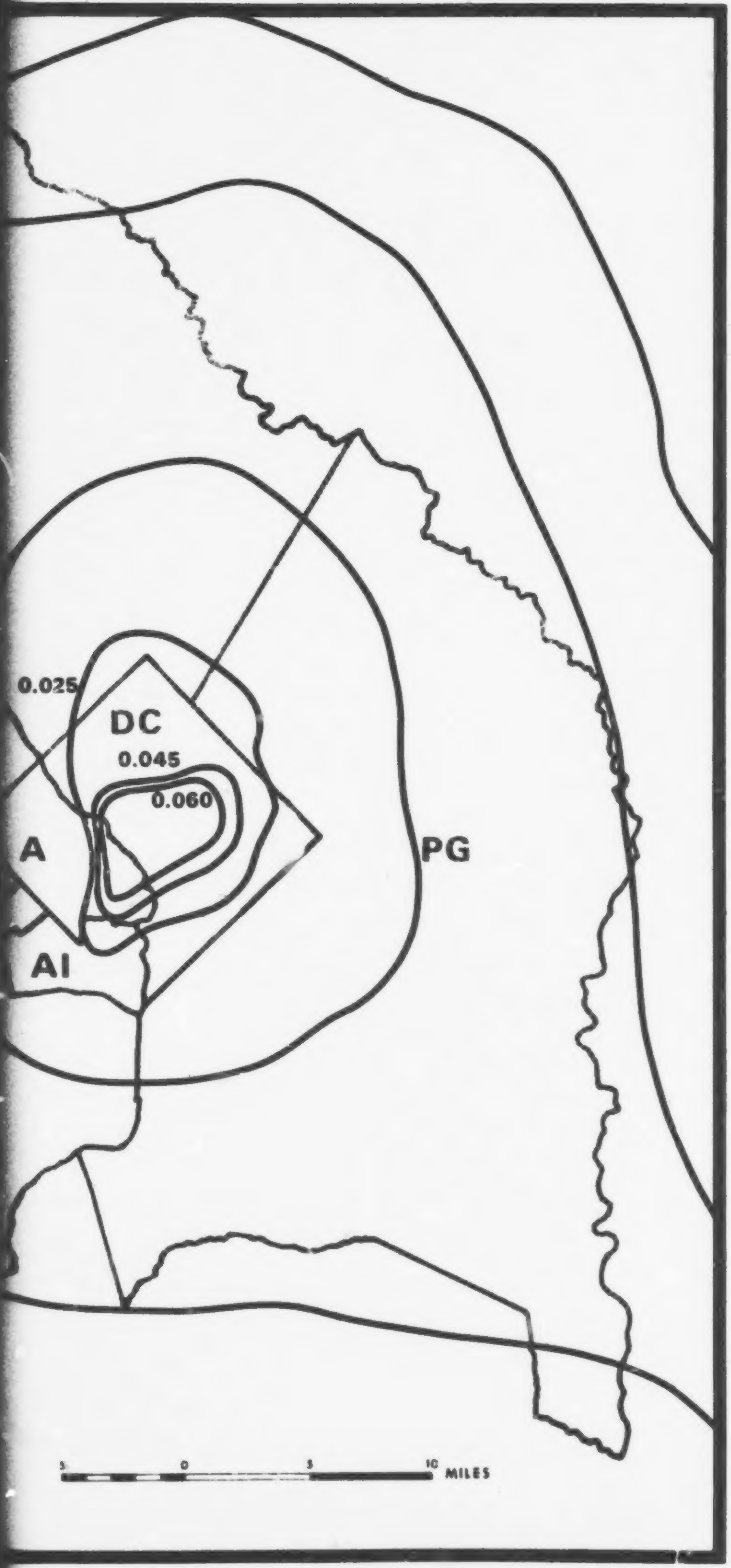

LEGEND

—	Iso-intensity Line
PPM	Parts Per Million (Annual Average)

NATIONAL CAPITAL AREA

A	Arlington County
AI	Alexandria
DC	District Of Columbia
F	Fairfax County
Fax	Fairfax
FC	Falls Church
L	Loudoun County
M	Montgomery County
PG	Prince Georges County
PW	Prince William County

EXHIBIT IV-5

CONCENTRATIONS OF SULFUR OXIDES (PPM)

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Washington, D.C.

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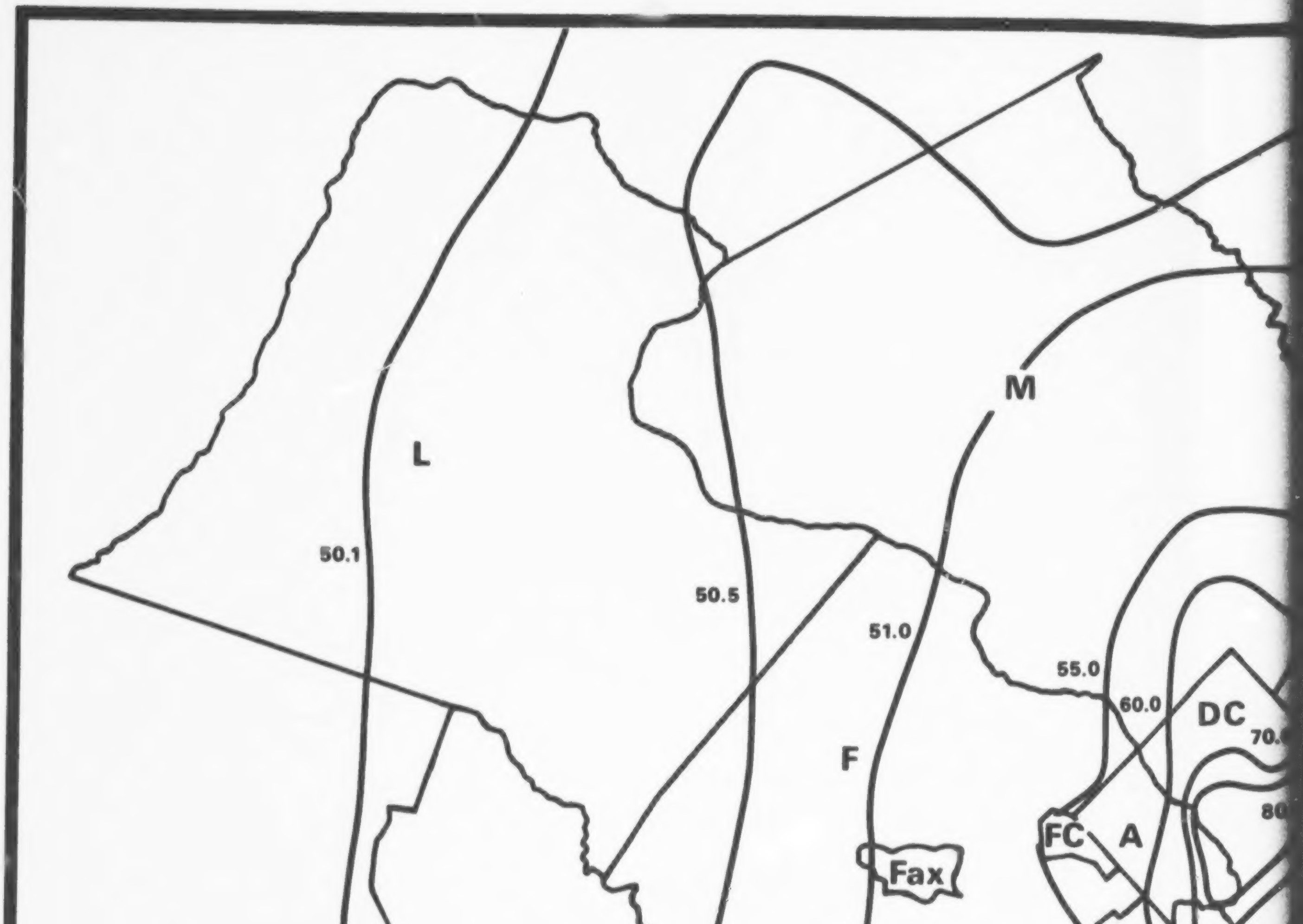
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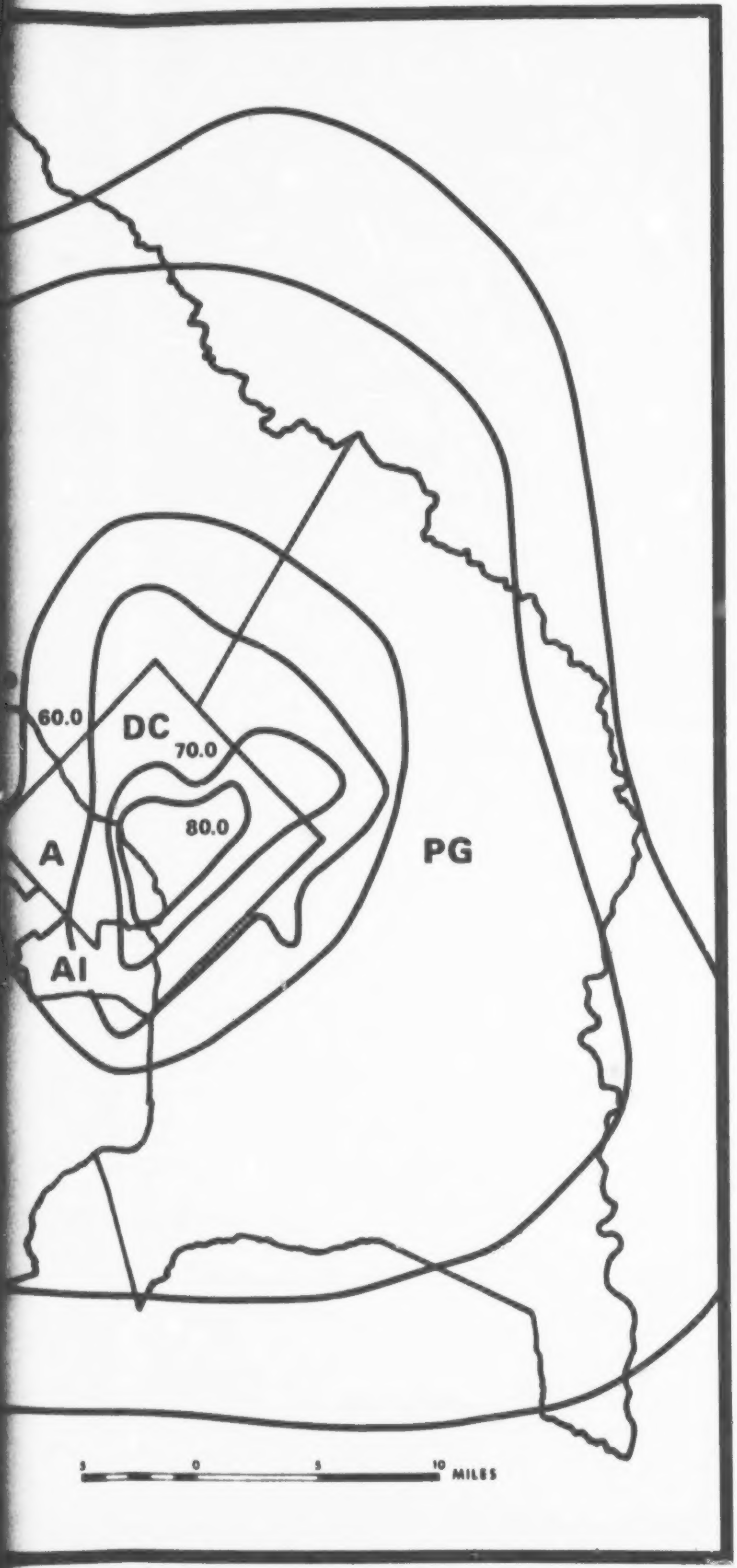

LEGEND

——	Iso-intensity Line
μGm/M^3	Micrograms Per Cubic Meter (Annual Average)

NATIONAL CAPITAL AREA

A	Arlington County
Al	Alexandria
DC	District Of Columbia
F	Fairfax County
Fax	Fairfax
FC	Falls Church
L	Loudoun County
M	Montgomery County
PG	Prince Georges County
PW	Prince William County

EXHIBIT IV-6

CONCENTRATIONS OF SUSPENDED PARTICULATES (μGm/M^3)

ERNST & ERNST
Washington, D.C.

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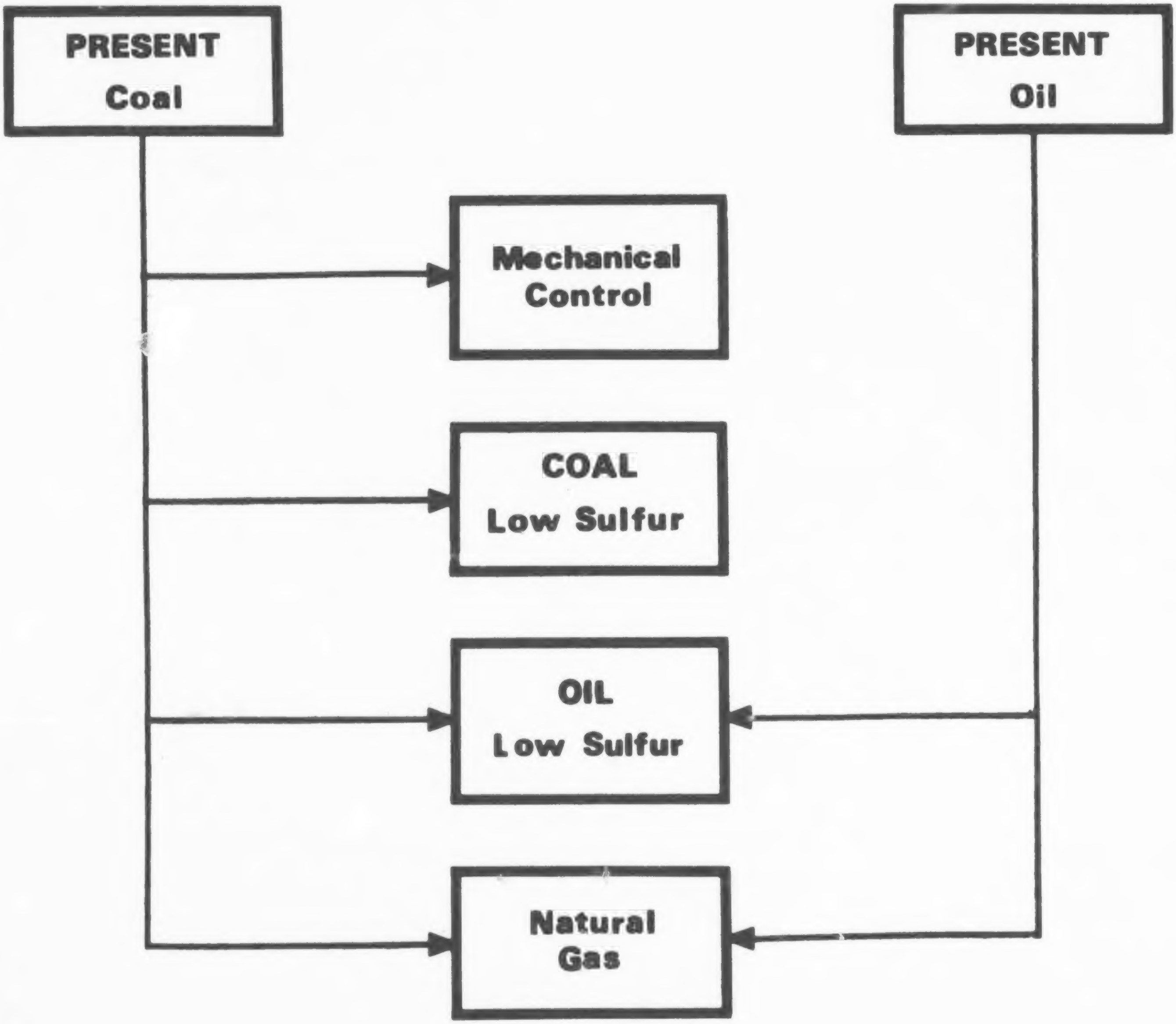
EXHIBIT IV-7

ALTERNATIVES FOR PARTICULATE AND SULFUR OXIDES EMISSION CONTROL (STATIONARY SOURCES)


PRESENT
Coal
PRESENT
Oil
Mechanical Control
COAL
Low Sulfur
OIL
Low Sulfur
Natural Gas

For other incinerators, upgrading is limited to installation of a multichamber incinerator with a wet spraying device, or in the case of larger incinerators, installation of a wet scrubbing device.

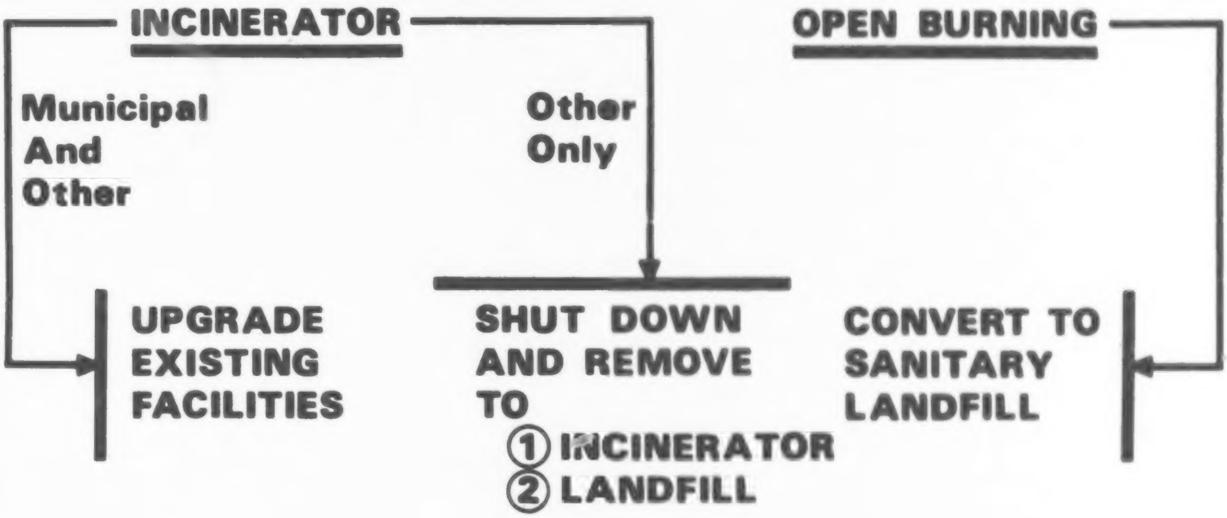
Shutdown - This applies only to apartment, commercial, and industrial incinerators. It involves closing down existing incineration facilities and hauling or trucking the solid wastes to another site for disposal. Removal would be to new landfills or incinerators.

Conversion to Sanitary Landfills - This alternative consists of conversion of an open-burning dump site from open-burning to operation as a sanitary landfill. It requires that all burning of solid waste be stopped and that waste handled at the site be buried.

Exhibit IV-8 summarizes the control alternatives available to each type of refuse incineration source considered.

EXHIBIT IV-8

CONTROL TECHNOLOGY ALTERNATIVES REFUSE INCINERATION



Control Technologies Not Considered - Not included as emission control technologies are nuclear power plants to replace present steam electric generating stations; construction of higher smoke stacks; relocation or closing down of any source, except incinerators and open-burning areas; improved maintenance of facilities; industrial process changes; use of liquified natural gas, gasified coal, fuel cells, or exotic fuels; and changing land use or zoning policies. Nor is the time phasing of controls considered; that is, it is assumed that all controls are applied instantaneously and all sources are controlled concurrently. Some or all of these alternatives may be both practical and available means of improving air quality in the National Capital Area, but their consideration in this study was not possible.

Emission Rates - Exhibits IV-9 and IV-10 give the emission rates of SO_x and SP for the various types of stationary combustion sources and incinerators, respectively. These rates are all expressed in pounds per million Btu, so that comparisons of emission rates of the various fuels for a given furnace size can be readily made.

Cost Analysis - The bulk of the cost analysis effort is necessarily manual, since each point source usually has some major peculiarity, such as existing controls, requiring special analysis of the alternative combinations of fuels and control devices which apply. However, computation was assisted in the study by the semi-automation of the formulas given in Appendix C for the Olivetti Programma desk top computer. These Olivetti programs are referred to collectively as the CAP program in Exhibit IV-2. The output of this analysis is the detailed listing of the compatible combinations of fuel and hardware emission control technologies available to each source. These alternatives are further broken down by discrete control levels. For example, a coal-fired source might have the following discrete control levels:

	Control Technology		Control Level
1.	Substitute low sulfur coal (reduces SO_2 emissions)	1.	2% sulfur
		2.	1.5% sulfur
		3.	1.0% sulfur
2.	Install precipitator (reduces particulate emissions)	1.	Low efficiency
		2.	Medium efficiency
		3.	High efficiency
3.	Switch to oil (reduces SO_2 and particulate emissions)	1.	2% sulfur
		2.	1.5% sulfur
		3.	1.0% sulfur
4.	Switch to natural gas (reduces SO_2 and particulate emissions)	1.	Interruptible (95% gas, 5% light oil)
		2.	Firm (100% gas)

In the above purely illustrative example there are a total of 11 control levels, but there are more than 11 emission control combinations. Technologies 1 and 2 may or may not be used together; thus, there are actually 17 emission control combinations, or states, available to the source. These individual source control technologies, emissions, costs, and permissible control states are used as input to the SORT program (see Appendix D). The enumeration of all possible states with their corresponding emissions, costs, and cost ranges is done in this program. The most efficient states are selected from the SORT program output to be used in later analysis. Chapter V, "New York-New Jersey Study," contains detailed examples of the use of the SORT program.

EXHIBIT IV-9

POLLUTANT EMISSION RATES

STATIONARY COMBUSTION SOURCES[a]

Fuel Type	Furnace Type	Pounds of Emissions per Unit[b]		Heat Content Per Unit in Million BTU	Pounds of Emission per Million BTU	
		Sulfur Dioxide[c]	Suspended Particulate[d]		Sulfur Dioxide	Particulate
Coal		38S				
	Pulverized - general		16A	23	1.7S	0.70A
	Dry bottom		17A			0.74A
	Wet bottom					
	Without reinjection		13A			0.57A
	With reinjection		24A			1.0A
	Cyclone		2A			0.087A
	Spreader stoker					
	Without reinjection		13A			0.57A
	With reinjection		20A			0.87A
	All other stokers		5A			0.22A
	Hand-fired equipment		20			0.87A
Fuel Oil[e]						
#6	Small sources	157S	12	150	1.0S	0.080
	Large sources	157S	8			0.053
#5	Small sources	157S	12	148	1.1S	0.081
	Large sources		8			0.054
#2	Small sources	157S	12	138	1.1S	0.090
	Large sources		8			0.058
#1	Small sources	157S	12	135	1.2S	0.089
	Large sources		8			0.060
Natural Gas[f]		0.4		950		
	Power plants		15			0.016
	Industrial boilers		18			0.019
	Domestic and commercial heating units		19			0.020

[a] Guntis Ozolins and Raymond Smith, A Rapid Survey Technique for Estimating Community Air Pollution Emissions, (Cincinnati: U.S. Department of Health, Education, and Welfare, Public Health Service, October 1966).

[b] The units of measure are: Coal - 1 ton; fuel oil - 1,000 gallons; natural gas - 1 million cubic feet.

[c] S = percent of sulfur in fuel.

[d] A = percent of ash in coal.

[e] A small source is a furnace of 1,000 horsepower or less. A large source, more than 1,000 horsepower.

[f] A power plant furnace generates more than 100 million BTU per hour; an industrial boiler, 10 million to 100 million BTU per hour; a domestic or commercial unit, less than 10 million BTU per hour.

EXHIBIT IV-10

POLLUTANT EMISSION RATES

INCINERATION AND OPEN BURNING[a]
(Pounds per ton of refuse burned)

	Incineration						Open Burning	
		Industrial and Commercial			Domestic Single Chamber			
Pollutant	Municipal Multiple Chamber	Single Chamber	Multiple Chamber	Flue-Fed Apartment Incinerator	Without Auxiliary Gas Burning	With Auxiliary Gas Burning	Burning Dump	Backyard Burning
Sulfur Oxides	1.9	N/A	1.8	0.5	2.0	2	1.2	0.8
Particulate	6[b] 12[c]	20 - 25	4	26	39	6	47	150

N/A = Not applicable.

[a] Guntis Ozolins and Raymond Smith, A Rapid Survey Technique for Estimating Community Air Pollution Emissions, (Cincinnati: U. S. Department of Health, Education and Welfare, October 1966), pp. 72, 73.

[b] For incinerator with spray chamber.

[c] For incinerator without spray chamber.

Strategies

As mentioned earlier three strategies for areawide abatement were simulated in this study:

a. The set of emission control states which achieves selected air quality levels at the least total cost to the whole National Capital Area

b. Restricting fossil fuels to 1 percent sulfur by weight or less

c. "Universal abatement," by which all sources simultaneously take successively greater steps in reducing pollutant emissions until all applicable control states stipulated for each source have been employed to achieve the maximum reduction possible

The estimated cost of this strategy comprises increased fuel costs and, in the case of fuel switching, boiler conversion costs, including necessary piping, ducts, storage facilities, etc. The approach does not take into consideration the availability of low sulfur fuels or increases in low sulfur fuel prices due to increased demand.

The restriction of fuels burned to 1 percent sulfur does not necessarily lessen emissions of particulate. The approach, however, allowed the addition of control technologies to reduce particulate emissions.

Universal Abatement - In this model up to six SO_x emission control states per source were provided. The sixth state being the maximum emission control which would be effected by the source for the SO_x control technologies stipulated.

Four successive states of particulate control were also chosen for the source types. Thus, areawide reduction in the concentration of both pollutants and the associated control costs were calculated. Since up to six SO_x control states and up to four particulate control states were provided for each source, as many as 24 distinct control states were possible for each source to control SO_x and particulate simultaneously.

Least Cost - Each of the emission sources was assigned one to twelve dominant control states listed on the SORT program (see Appendix D and the examples in Chapter V). Also input to the analysis were the costs of each postulated state.

The analysis consisted of the use of a computerized zero-one integer programming algorithm (INTCODE, see Appendix D). One constraint was imposed: that the maximum concentration of SO_x and particulate could not exceed specified levels (see Exhibit IV-1). The cost was minimized, then, in such a way that the concentrations of each pollutant would nowhere exceed the air quality levels selected.

Final Analysis

To use the SORTCON program, one emission control state is selected for each source in conformance with the strategy to be simulated, and the program then computes the resultant concentrations and costs. For example, under the 1 percent sulfur fuel restriction strategy, only SO_x control states involving fuels of 1 percent sulfur or less are candidates for selection, and from these only the lowest cost state is selected for the SORTCON. In this way answers are developed for such questions as "What would be the cost and effectiveness if the burning of fuels of no greater than 1 percent sulfur content were mandatory?" or "What would be the cost and effectiveness of having all power sources burn natural gas?" etc.

The INTCODE program answers such questions as "What is the cheapest overall way to reduce concentrations at every receptor point to no more than 0.015 ppm of SO_x and 75 μgms/m^3 of particulate?" or "What is the greatest reduction that can be achieved in the highest pre-abatement concentration of SO_x?" Thus, the SORTCON and INTCODE programs are the means of producing the cost and pollutant concentration data associated with each areawide abatement strategy. The last stage of analysis then is to analyze results and compare the costs and effectiveness of the abatement strategies.

COST-EFFECTIVENESS RESULTS

In the previous model city studies (Chapter II and III), several measures of effectiveness - annual average maximum concentration of the pollutants, total emissions, human exposure - were considered. For this study the measure of effectiveness was the reduction of maximum SO_x and SP concentrations to a pair of air quality levels selected from Exhibit IV-1.

Exhibit IV-11 summarizes the costs and effectiveness of the three simulated abatement strategies.

Exhibit IV-11 sets forth the results of each simulation, or calculation point, denoted by "C.P.," of the universal abatement strategy. The C.P. notation identifies the type of control simulated and the level of control at each emission source. The first digit of each number indicates a degree, 1 through 6, of SO_x control. Four degrees of SP control were simulated and are indicated by a number 1 through 4 following the decimal point in the C.P. number. Thus, C.P. 2.0 is degree 2 of SO_x control without SP control, C.P. 1.3 represents the first degree of SO_x control and the third degree of SP control, and maximum control is the highest degree of both, D.P. 6.4. Each degree of control represents a set of control states imposed on the sources simulated.

As Exhibit IV-11 shows, the least cost solution is by far the most effective for the cost. In fact, the first air quality level, a SO_x maximum of 0.035 ppm and a SP maximum of 75 μgms/m^3, is reached at no net additional cost for the National Capital Area, and perhaps at a

90

EXHIBIT IV-11

ESTIMATED ADDITIONAL ANNUAL COSTS TO REDUCE SO_x AND SP [a] EMISSIONS IN WASHINGTON, D.C. BY SIMULATED ABATEMENT STRATEGIES

(1967 dollars in millions)

	Peak Annual Average Concentrations Reduced to		% Emission Reduction		Cost [b]
Strategy	ppm SO_x	μgms/m^3 SP	SO_x	SP	
Pre-abatement	0.063	83	-0-	-0-	-0-
Least Cost	0.035	75	10	10	\$(0.05) [c]
	0.025	75	18	8	2.40
	0.015	75	27	8	5.30
1% Sulfur Fuel Restriction	0.031	83 (no reduction)	38	-0-	5.75
Universal Abatement					
C.P. [d] 1.0	0.049	82	27	1	3.80
C.P. 1.1	0.049	74	27	50	10.25
C.P. 1.2	0.049	73	27	53	10.85
C.P. 1.3	0.049	73	27	53	10.85
C.P. 1.4	0.049	72	27	54	11.20
C.P. 2.0	0.032	81	45	17	12.15
C.P. 3.0	0.022	81	81	30	23.95
C.P. 4.0	0.013	78	90	31	32.70
C.P. 5.0	0.012	78	90	32	33.90
C.P. 6.0	0.012	78	90	32	35.70
Maximum Control [e] (C.P. 6.4)	0.012	72	90	56	42.65

[a] SO_x = sulfur oxides; SP=suspended particulate.

[b] Rounded to nearest \$50,000 (\$0.05 million).

[c] Negative total cost because Federal heating plants shift to cheaper fuels with lower sulfur and ash content.

[d] C.P.= calculation point. See text for explanation of C.P. notation.

[e] Lowest peak attainable with stipulated emission control alternatives.

slight negative cost. By the 1 percent sulfur fuel restriction it would cost nearly $6 million to achieve only a slightly greater reduction in sulfur oxides, 0.031 ppm, and the universal abatement strategy level most nearly comparable, calculation point 2.0, reaches a maximum annual average SO_x concentration level of 0.032 ppm at a cost of $12.15 million. Further, to reduce the annual average SP level to 75 $\mu gms/m^3$ would cost about $7 million annually in addition to either the 1 percent sulfur restriction strategy cost or the $12.15 million of the universal abatement strategy cost. It is apparent that the cost of reducing both SO_x and SP by the least cost strategy is far less than the cost of the other strategies to reduce only the maximum concentration of SO_x.

The second and third air quality levels of SO_x (0.025 and 0.015 ppm) cannot be reached by the 1 percent sulfur fuel restriction. A maximum annual average concentration of 0.015 ppm of SO_x and 75 $\mu gms/m^3$ of SP appears feasible at a cost of $5.30 million annually by the least cost strategy. Compare that amount with the $32.70 million annual cost of calculation point 4.0 of the universal abatement strategy, which attains maximum concentrations of 0.013 ppm of SO_x and 78 $\mu gms/m^3$ of SP. Even calculation point 3.0 costs more than four times as much as the highest air quality level by least cost and falls short of attaining these levels (0.022 ppm versus 0.015 ppm, and 81 $\mu gms/m^3$ versus 75 $\mu gms/m^3$).

Exhibit IV-11 shows the percentage of reduction of total annual average emissions as well as the reduction in annual average maximum concentrations. In this study effectiveness was measured by the reduction of the maximum concentration of the pollutants, and that reduction related to cost. The effectiveness of a strategy may also be considered in terms of the efficiency of its emission reduction, that it, the reduction in emissions required to lower maximum concentration levels.

Compare, for example, the first least cost level, which attains a maximum SO_x concentration of 0.035 ppm; the 1 percent sulfur fuel restriction, 0.031 ppm; and the universal abatement calculation point 2.0, 0.032 ppm. The percentages of SO_x reduction to attain these levels are 10 percent, 38 percent, and 45 percent, respectively. Further, the least cost strategy can attain the highest air quality level, 0.015 ppm of SO_x, through a 27 percent reduction in SO_x emissions. This 27 percent reduction is less than the 38 and 45 percent reductions by the other two strategies to abate only to higher maximum concentrations.

There is some value, of course, in abating any emissions, in that ambient air concentrations are reduced somewhere, if not at the point of maximum concentration. It is not necessary to discount emission reduction which does not expediently lower measured levels of maximum concentration of pollutants. However, when the measure of effectiveness is defined as reduction of the maximum concentration of a pollutant as in this study, the possible strategies must be evaluated for economy and selectivity accordingly. By these measures, the least cost strategy is again the most effective.

9v

DISTRIBUTION OF EMISSION CONTROL COSTS

Exhibit IV-12 shows the distribution of abatement costs to the classes of users under the three strategies. Only two representative calculation points of the universal abatement strategy were used in preparing the exhibit, but they allow comparisons to be made.

The cost of the 1 percent sulfur fuel restriction strategy falls mainly on two source classes: power plants and aggregated area sources. The percentage of the estimated cost to power plants of the total cost is proportional to the percentage of total SO_x emitted by power plants. (See Exhibit IV-2 for emissions by source class.) However, the aggregated area sources, responsible for approximately 21 percent of total SO_x emissions, would incur 43 percent of the abatement costs. The Federal Government, which is the third largest emitter of SO_x , would actually realize a cost saving by changing to lower sulfur fuels because of the favorable fuel prices available to the Government.

Costs by class for the universal abatement strategy are not proportional to emissions. Power plants, which are responsible for the greatest portion of the emissions, would incur a greater part of the cost, but not a directly proportional amount. They emit 63 percent of the total Area SO_x emissions and 27 percent of the SP emissions but would incur only about one-half of the abatement costs. Again, aggregated sources would incur percentages of costs greater than their percentages of contributions to emissions.

The least cost strategy to reach the first air quality level requires a negligible or negative cost from all sources but one; that source, municipal incinerators, would still incur less cost than it would at some calculation points of the universal abatement strategy. To reach the second and third air quality levels, the greatest part of the cost is incurred by aggregated area sources. In this respect, the strategy is extremely disproportional. However, two pertinent observations might be made:

(1) The sulfur fuel restriction and the universal abatement strategies, which would seem to distribute the burden of abatement arbitrarily, in fact would exact costs from sources disproportionate to their contributions to total emissions.

(2) Under the least cost strategy most of the cost burden is on area sources. However, for each of the three levels the cost to the area sources is still lower than that under the universal abatement strategy. Further, the cost to nearly every source to reach any one of the air quality levels is lower by the least cost strategy than by the universal abatement strategy.

EXHIBIT IV-2

DISTRIBUTION OF ESTIMATED ADDITIONAL ANNUAL COSTS[a] AMONG EMISSION SOURCE CLASSES TO ACHIEVE SELECTED AIR QUALITY LEVELS FOR SO_x AND SP IN THE WASHINGTON, D. C. AREA

(1967 dollars in millions)

Emission Source Class	Resultant Peak Annual Average Concentrations						
	1% Sulfur Fuel	Least Cost			Universal Abatement		Maximum Control
	0.031 ppm SO_x no SP control	0.035 ppm SO_x 75 μGms/M^3SP	0.025 ppm SO_x 75 μGms/M^3SP	0.015 ppm SO_x 75 μGms/M^3SP	0.049 ppm SO_x 74 μGms/M^3SP	0.022 ppm SO_x 81 μGms/M^3SP	0.012 ppm SO_x 72 μGms/M^3SP
Point Source Classes[b]							
Apartments	0.35	[c]	[c]	0.25	[c]	0.40	2.35
Commercial	0.10	[c]	[c]	[c]	[c]	0.30	0.35
Federal Government	(0.40)[d]	(0.25)[d]	(0.25)[d]	[c]	(0.30)[d]	6.40	8.35
Hospitals	0.05	[c]	[c]	[c]	[c]	1.00	1.05
Hotels	0.05	[c]	0.05	0.05	[c]	0.05	0.25
Municipal incinerators	-0-	0.10	0.10	0.10	0.20	-0-	0.70
Open burning areas	-0-	-0-	-0-	-0-	1.75	-0-	1.75
Power plants	3.20	-0-	[c]	0.70	4.50	12.55	18.75
Process industries	[c]	[c]	[c]	[c]	[c]	[c]	[c]
Universities	0.05	[c]	[c]	[c]	0.05	0.60	0.90
Aggregated Area Sources[e]	2.45	[c]	2.35	4.10	4.05	2.55	8.20
Total	5.85	[c]	2.25	5.20	10.85	23.85	42.65

[a] Additional annual costs given to the nearest $50,000 (0.05 million).
[b] A point source emits over 100 tons of SO_x or particulate per year.
[c] Less than $25,000 per year.
[d] Net savings from shift to cheaper fuels.
[e] Sources which emit less than 100 tons of pollutants a year were combined into 13 aggregated sources by fuel use on activity class.

V. NEW YORK-NEW JERSEY STUDY

The purpose of this study, undertaken under Contract No. PH 86-68-37 with the National Air Pollution Control Administration, was to develop, under certain assumptions, broad estimates of the cost of reducing particulate and sulfur oxides (SO_x) emissions from several kinds of power plants, stationary combustion sources, and incinerators which may be found in the New York Metropolitan Area. A summary presentation of the results of this study was given to the New York Air Pollution Abatement Conference in February 1968.

OBJECTIVES

The objective of this study was to estimate the annual cost of reducing particulate and SO_x emissions from power plants, stationary combustion sources, and incinerators. This study differed from the other studies discussed in this report in that it was not a multiple-source analysis; that is, it was not an analysis of abatement strategies applicable to several sources in an area to improve air quality throughout the area. Rather, this study was concerned only with the cost and effectiveness of control technologies available to a source to reduce its own emissions. As a further distinction, the other studies analyzed strategies for many sources simultaneously to follow to reduce pollution impacts on receptors, while this study analyzed the cost-effectiveness of control technologies available to selected emission points without relating emissions to receptors. Accordingly, no meteorological data or source location was needed in this analysis.

Even though this study was concerned primarily with particulate pollution, discussion of particulate emission control from power plants and stationary combustion sources must involve discussion of the control of SO_x as well. The reason is that several of the technologies for SO_x control also involve control of particulates. In general, therefore, it is not possible to estimate the cost of controlling each pollutant independently. Emission control technologies and their costs are discussed in terms of the simultaneous control of both pollutants.

Nine source models, typical of the power plants and stationary combustion sources found in the New York Metropolitan Area, were simulated. The SORT program (see Appendix D for flow chart and listing) was used to assign the feasible control states - combinations of control technologies - for each of these sources and to calculate the estimated annual cost of each state.

INPUTS

This analysis required three types of input:

(1) Major characteristics of the area emission source models, including

- average annual emissions of SO_x and particulate (see Exhibits IV-9 and IV-10)
- fuel and heat requirements (see Exhibit V-1)
- number of furnaces by type (see Exhibit V-1)
- rate of gaseous throughput (see Exhibit V-1)

No existing controls were assumed.

(2) Cost, sulfur and ash content, heat content, and consumption of fuel oils (residual and distillate), coal (bituminous and anthracite), coke, and natural gas (the data from Exhibits III-7 through III-9 apply)

(3) Devices for particulate and SO_x emission control: their types, sizes, compatibility with sources, collection efficiencies, and capital, operating and maintenance costs (the data from Exhibits III-10 through III-16 apply)

ANALYSIS

Meteorological Analysis

This study did not analyze areawide abatement, nor the concentrations resulting from multiple-source emissions; therefore, no meteorological analysis was required.

Abatement Analysis

Exhibit V-2 shows the fuel and hardware technologies assumed to be available to the uncontrolled power plants, stationary combustion sources, and incinerator modeled in this study. In addition to the technologies shown, purchasing electricity directly from a utility was considered as an available alternative for sources generating electrical power. Some technologies, such as switching to atomic energy, were not considered.

For a discussion of the fuel and hardware technologies indicated in Exhibit V-2 see the discussion "Abatement Analysis" in Chapter III. See Appendix C for the applicable cost-effectiveness computations.

96

EXHIBIT V-1

SOURCE MODEL CHARACTERISTICS[a]

Source Model	Source Model Number	Type of Fuel	Gross Annual Btu Input (billions)	Rated Capacity Megawatts	Number of Furnaces	Scfm of Exhaust Gas Volume Per Unit	Fuel Quantity	Emissions SOx	(gm/sec) Particulate
Power Plant	1	Coal (Cyclone)[b]	44,100	800	4	450,000	1,700,000 tons	1,854.1	414.7
	2	Oil[b]	42,000	800	4	500,000	280,000,000 gals.	1,581.7	32.2
	3	Coal (Pulverized Dry Bottom)[b]	11,100	200	4	140,000	427,000 tons	466.7	835.1
Stationary Combustion Source	4	Coal (Spreader Stoker)	100	N/A	1	3,100	3,850 tons	4.2	6.5
	5	Oil	400	N/A	2	20,000	2,700,000 gals.	15.1	0.3
	6	Oil	50	N/A	1	6,300	335,000 gals.	1.9	0.1
	7	Coal (Spreader Stoker)	200	N/A	3	25,000	7,700 tons	8.4	12.9
	8	Oil	300	N/A	4	37,500	2,000,000 gals.	11.3	0.2
Municipal Incinerator	9	Natural Gas	N/A	N/A	2	236,000	250 tons/day refuse	9.4	592.4

[a] Developed from information furnished by the U. S. Public Health Service N.Y.-N.J. Abatement Activity.

[b] Furnaces assumed to be capable of using coal, oil, or natural gas interchangeably.

N/A = Not applicable.

EXHIBIT V-2

ALTERNATIVES FOR SO_x AND PARTICULATE EMISSION CONTROL (COMBUSTION SOURCES)

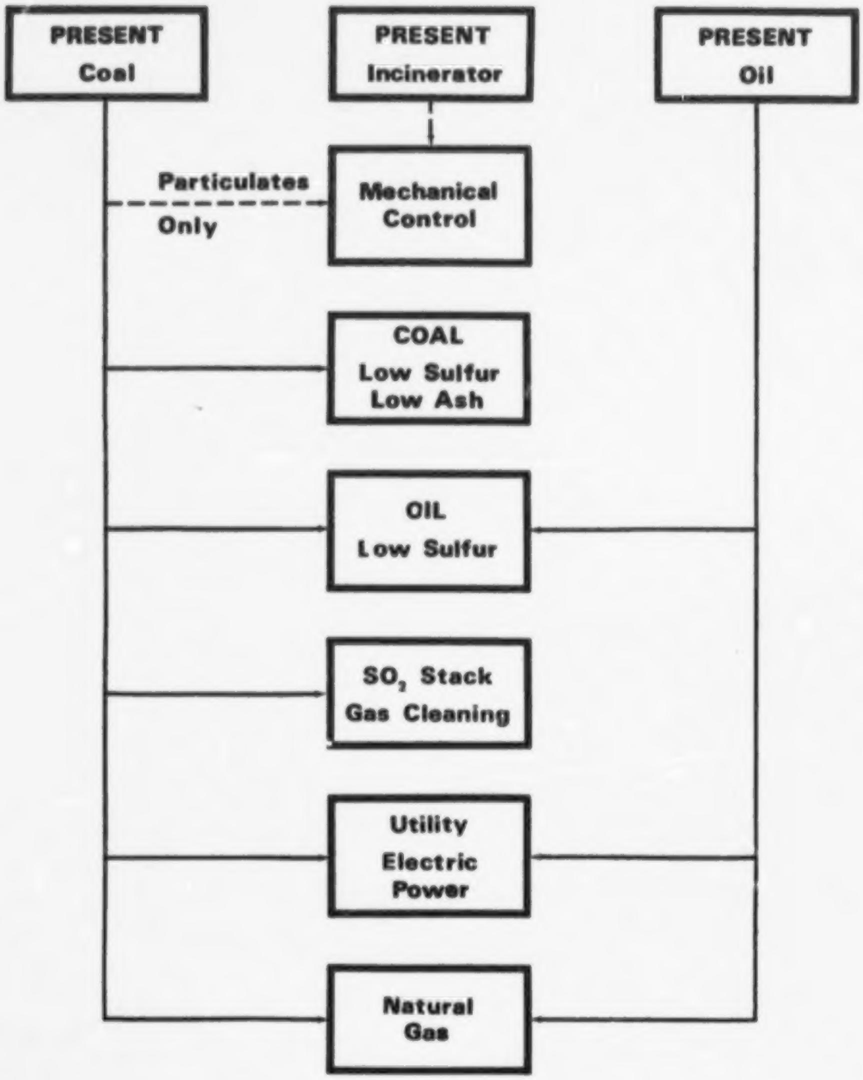

PRESENT
Coal
PRESENT
Incinerator
PRESENT
Oil
Particulates
Only
Mechanical
Control
COAL
Low Sulfur
Low Ash
OIL
Low Sulfur
SO_2 Stack
Gas Cleaning
Utility
Electric
Power
Natural
Gas

Exhibit V-3 is a detailed listing of the control technologies stipulated for four of the nine source models in the analysis. The sources are two power plants - one coal-burning and one oil-burning, an industrial combustion source, and a municipal incinerator. These four models were chosen to demonstrate the analysis because they represent the cover the spectrum of source types by fuel type, size, and control technologies used in the study.

Each source model, as Exhibit V-3 shows, was assigned a number of feasible control technologies. For example, source model 1, a power plant, has four technologies: fuel substitution, fuel switching, collection equipment, and SO_2 stack gas cleaning. Within each technology are a number of control levels. The level of a technology is its relative degree of anticipated effectiveness: levels of fuel substitution are defined by the sulfur and ash contents of the proposed fuels; levels of collection equipment correspond to the different collection efficiencies of the equipment.

It is possible to combine two or more technologies for pollution control. Therefore, there may be many control states (i.e., control technology combinations) resulting. The number of states possible for each of the example source models is also shown in Exhibit V-3.

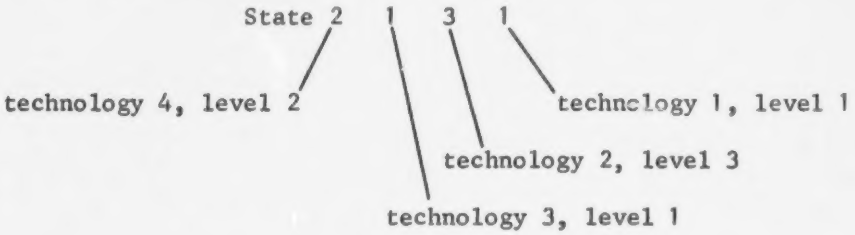
The control states - those shown on Exhibit V-3 plus those possible for the other five source models - were entered into the SORT program. The costs of the control states were calculated by the methods shown in Appendix C. Briefly, fuel substitution and switching costs are determined by the differential cost per Btu of the new fuel times the required annual Btu input. Equipment costs are made up of the equipment purchase price, an installation cost which is a percentage of the purchase price, and estimated annual operating and maintenance costs. The capital cost is depreciated on a straight-line basis over a 15-year period. In this study, no allowance was made for interest, taxes, or other capital related costs.

The SORT program output gives the following for each source:

- Sorting of control states into "dominant" and "nondominant". A state is dominant if no other state achieves an equivalent or greater emission reduction at a lower cost
- Cost of each state: fixed, operating and fuel, and total
- Percent reduction of pollutant emissions and resultant emissions for each control state

The computer output for the example models in Exhibit V-3 (sources 1, 2, 5, 9) is transcribed in Exhibit V-4. The states listed are referenced by a key. The number of digits in the key corresponds to the number of technologies posed for a source, e.g., source 1 has a 4-digit key, and Exhibit V-3 shows that four technologies were used for that state. The technologies are read from right to left. Each digit indicates the level of application of the technology; level 1 is the base, or present, level.

Example, source 1:



The control combination for the listing may be read on Exhibit V-3 through this key.

From Exhibit V-4 the cost and effectiveness of each dominant control state was ranked according to increasing cost. The five most efficient states for each source were selected to cover the spectrum of possible costs and emission reductions.

Exhibit V-5 gives these selected states for each source and the associated percentage reduction in uncontrolled SO$_x$ and particulate emissions.

COST-EFFECTIVENESS RESULTS

In Exhibits V-6 through V-13 the percentage reduction in particulate emissions is shown on the vertical axis and the percentage reduction in SO$_x$ emissions is shown on the horizontal axis. The numbered points give the simultaneous particulate and SO$_x$ emission reductions effected by the correspondingly numbered emission control alternatives. The estimated annual cost of each control alternative is given in bold type at the bottom of each figure. The middle estimate is considered to be the most likely cost on the basis of the data available. Again, these costs are in addition to a present annual operating cost. High and low estimates are also given to reflect both uncertainties and variances in current prices for fuels and for purchase, installation, maintenance, and operation of mechanical controls.

Source Model 1

Source model 1 (Exhibit V-6) is an 800 megawatt power plant burning 2 percent sulfur coal. Alternative 1 reduces particulate emissions by 98 percent for an estimated cost of $369,000 annually. The low estimate is $139,000 and the high estimate is $741,000.

Source Model 2

Source model 2 (Exhibit V-7) is also an 800 megawatt power plant, but it uses 2.5 percent sulfur residual oil as its fuel. The estimated annual costs of the four control alternatives increase as the sulfur content of the substituted oil decreases. Since the particulate emission factor of residual oil will probably not change with lower sulfur content, this is a case where all of the cost is allocable to SO_x control. The annual costs range from $630,000 to $5,250,000.

Source Model 3

Source model 3 (Exhibit V-8) is a 200 megawatt power plant burning 2 percent sulfur coal. The five control alternatives and the emission reductions effected are similar to the coal-burning 800 megawatt plant first shown (source model 1), except that Alternative 5 is a switch to natural gas. The annual costs range from $117,000 to $1,110,000.

Source Model 4

Source model 4 is an industrial stationary combustion source burning 2 percent sulfur coal with a gross annual input of 100 billion Btu, which represents 3,850 tons of coal. The five control alternatives shown in Exhibit V-9 span the full range of annual costs.

Notice the wide cost disparity between Alternatives 4 and 5, but the small difference in the high percentage of reduction. The disparity is caused by the normally lower rate for obtaining natural gas on an interruptible basis (Alternative 4), rather than on a firm basis (Alternative 5).

Source Model 5

This industrial stationary combustion source model (Exhibit V-10)uses 2.5 percent sulfur residual oil and has a gross annual input of 400 billion Btu (2 million gallons). It has been assumed that this source produces steam to generate electricity for use in an industrial process.

Alternative 4, purchasing natural gas on an interruptible basis, creates an apparent distortion in emission reductions. A 63 percent particulate reduction is shown when switching from 2.5 percent sulfur residual oil to gas. In source model 4, shown previously, switching from 2 percent coal to natural gas causes a 99 percent reduction in particulate emissions. The explanation of the difference lies in the fact that for uncontrolled sources the particulate emission rate for coal is higher than that for oil, while the particulate emission rate for natural gas is lower than both. When switching from coal to natural gas the percentage reduction in particulate emissions is greater than when switching from residual oil to natural gas.

Source Model 6

Exhibit V-11 shows results of an analysis of reducing particulate and SO_x emissions from a model of an apartment house heat generating plant using residual oil with a gross annual input of 50 billion Btu (335,000 gallons). Alternatives 1, 2, and 3 represent the substitution of residual oil of decreasing sulfur content. Alternatives 4 and 5 represent a switch to natural gas on an interruptible and a firm basis, respectively. The annual costs range from $1,000 to $40,000.

Source Model 7

This stationary combustion source (Exhibit V-12) is a model of heat generating facility for a commercial establishment. It burns truck-delivered coal with a gross annual input of 200 billion Btu (7,700 tons). Alternative 1, a switch to residual oil, gives a 99 percent reduction in particulate emissions and an 11 percent reduction in SO_x emissions. This alternative appears to reduce present annual costs by about $5,000. The reason for this is that the cost of coal delivered to small users, unable to accept large volume rail or barge deliveries, is higher on a Btu basis than residual oil. This result is based upon then current New York area fuel costs, as are all other results in this study.

Source Model 8

The emission reduction and cost results for another commercial stationary combustion source model, using residual oil with a gross annual input of 300 billion Btu (2 million gallons), are shown in Exhibit V-13. The estimated annual costs range from $5,000 to $235,000 for the control alternatives analyzed.

Source Model 9

Exhibit V-14 gives the estimated costs of controlling a municipal incinerator consisting of two refractory furnaces emitting through one stack. Each furnace burns 250 tons of refuse a day.

Subtracting the cost of Alternative 1 from the costs for Alternatives 2, 3, or 5 provides an estimate of the cost of adding a cyclone, electrostatic precipitator, or filter to an incinerator that already has a spray chamber.

EXHIBIT V-3

AVAILABLE CONTROL TECHNOLOGIES FOR SELECTED SOURCES

			Technologies				
		No. States				Effect on	
No.	Description	(Technology Combinations)	Tech. No.	Level No.	Description a/	SO2	Particulate
1	Power plant (coal)	72	1		Fuel substitution - coal	X	X
				1	Base state - 2.0% sulfur coal		
				2	1.5% sulfur		
				3	1.0% sulfur		
				4	0.5% sulfur		
			2		Fuel switch - residual oil		
				1	Base state - 2.0% sulfur coal	X	
				2	2.5% sulfur		
				3	2.0% sulfur		
				4	1.5% sulfur		
				5	1.0% sulfur		
				6	0.5% sulfur		
			3		Collection equipment		
				1	Base state - no equipment		X
				2	Low efficiency cyc.		
				3	Middle efficiency cyc.		
				4	High efficiency cycle		
				5	Low efficiency EP/high efficiency cyc.		
				6	Middle efficiency EP/high efficiency cyc.		
				7	High efficiency EP/high efficiency cyc.		
			4		SO_2 stack gas cleaning		
				1	Base state - no application		
				2	SO_2 stack gas cleaning	X	X
2	Power plant (oil)	5	1		Fuel substitution - residual		
				1	Base state - 2.0% sulfur coal	X	
				2	2.0% sulfur		
				3	1.5% sulfur		
				4	1.0% sulfur		
				5	0.5% sulfur		

---

a/ EP = electrostatic precipitator; cycle = cyclone.

Exhibit V-3, cont'd

No.	Description	No. States (Technology Combinations)	Technologies			Effect on	
			Tech. No.	Level No.	Description a/	SO2	Particulate
5	Industrial Combustion Source (oil)	23	1		Fuel substitution - residual		
				1	Base state - 2.0% sulfur coal	X	
				2	2.0% sulfur		
				3	1.5% sulfur		
				4	1.0% sulfur		
				5	0.5% sulfur		
			2		Collection equipment - not applicable b/		
			3		Fuel switch - natural gas	X	X
				1	Base state - 2.0% sulfur coal		
				2	Interruptible (No. 2 fuel oil)		
				3	Firm		
			4		Shutdown and purchase electric power		
				1	Base state		
				2	Shutdown and purchase	X	X
9	Municipal Incinerator	6	1		Particulate control		X
				1	Base state - no equipment		
				2	Baffled spray chamber		
				3	Spray chamber and cyclone		
				4	Scrubber		
				5	Spray chamber and EP		
				6	Spray chamber and fabric filter		

b/ Four levels of cyclone control were assigned to the source. The results were not used in the study, on the assumption that particulate emissions from oil are not considerable enough to be measured.

EXHIBIT V-4

SORT PROGRAM OUTPUT

Source No.	Key[a] (State)	Dom/ NonDom[b]	% Emission Reduction		Emissions (g/sec)		Estimated Added Annual Cost (000)
			SO_x	Particulate	SO_x	Particulate	
1	1111	D	0	0	1,854	414.7	$ 0
	2111	D	90	100	185.4	2.07	3,781
	1211	D	0	20	1,854	313.8	108.9
	1311	D	0	30	1,854	290.3	162.2
	1411	D	0	40	1,854	248.8	216.3
	1511	D	0	98	1,854	8.295	368.5
	1611	D	0	99	1,854	4.147	391.9
	1711	D	0	100	1,854	2.074	413.1
	1121	D	10	92	1,659	34.01	661.5
	2121	D	91	100	165.9	0.17	4,442
	1221	D	10	93	1,659	27.21	770.4
	1321	N	10	94	1,659	23.81	823.7
	1421	N	10	95	1,659	20.40	877.8
	1521	D	10	100	1,659	0.6802	1,030
	1621	D	10	100	1,659	0.3401	1,053
	1721	D	10	100	1,659	0.1700	1,075
	1131	D	27	92	1,346	34.42	1,323
	2131	D	93	100	134.6	0.1721	5,104
	1231	D	27	93	1,346	27.54	1,432
	1331	D	27	94	1,346	24.10	1,485
	1431	D	27	95	1,346	20.65	1,539
	1531	D	27	100	1,346	0.6885	1,691
	1631	D	27	100	1,346	0.3442	1,715
	1731	D	27	100	1,346	0.1721	1,736
	1141	D	45	92	1,023	34.84	2,205
	2141	D	94	100	102.3	0.1742	5,986
	1241	D	45	93	1,023	27.87	2,314
	1341	D	45	94	1,023	24.39	2,367
	1441	D	45	95	1,023	20.90	2,421
	1541	D	45	100	1,023	0.6967	2,573
	1641	D	45	100	1,023	0.3484	2,597
	1741	D	45	100	1,023	0.1742	2,618
	1151	N	63	92	691.6	35.25	4,189
	2151	D	96	100	69.16	0.1763	7,970
	1251	N	63	93	691.6	28.20	4,298
	1351	N	63	94	691.6	24.68	4,352
	1451	N	63	95	691.6	21.15	4,406
	1551	N	63	100	691.6	0.7050	4,558
	1651	N	63	100	691.6	0.3525	4,581
	1751	N	63	100	691.6	0.1763	4,603
	1161	N	81	91	350.4	35.67	6,174

EXHIBIT V-4 - CONTINUED

SORT PROGRAM OUTPUT

Source No.	Key[a] (State)	Dom/ NonDom[b]	% Emission Reduction		Emissions (g/sec)		Estimated Added Annual Cost (000)
			SO_x	Particulate	SO_x	Particulate	
1 (cont'd)	2161	D	98	100	35.04	0.1783	$9,955
	1261	N	81	93	350.4	28.53	6,283
	1361	N	81	94	350.4	24.97	6,336
	1461	N	81	95	350.4	21.40	6,390
	1561	N	81	100	350.4	0.7133	6,542
	1661	N	81	100	350.4	0.3567	6,566
	1761	N	81	100	350.4	0.1783	6,587
	1112	D	25	3	1,391	402.7	441.0
	2112	D	93	100	139.1	2.014	4,222
	1212	D	25	22	1,391	322.2	549.9
	1312	D	25	32	1,391	281.9	603.2
	1412	D	25	42	1,391	241.6	657.3
	1512	D	25	98	1,391	8.054	809.5
	1612	D	25	99	1,391	4.027	832.9
	1712	D	25	100	1,391	2.014	854.1
	1113	D	50	18	927.0	341.7	3,528
	2113	D	95	100	92.70	1.709	7,309
	1213	D	50	34	927.0	273.4	3,637
	1313	D	50	42	927.0	239.2	3,690
	1413	D	50	51	927.0	205.0	3,744
	1513	N	50	98	927.0	6.835	3,896
	1613	N	50	99	927.0	3.417	3,920
	1713	D	50	100	927.0	1.709	3,941
	1114	N	75	41	463.5	243.9	6,836
	2114	N	98	100	46.35	1.219	10,621
	1214	N	75	53	463.5	195.1	6,944
	1314	N	75	59	463.5	170.7	6,998
	1414	N	75	65	463.5	146.3	7,052
	1514	N	75	99	463.5	4.877	7,204
	1614	N	75	99	463.5	2.439	7,227
	1714	N	75	100	463.5	1.219	7,249

EXHIBIT V-4 - CONTINUED

SORT PROGRAM OUTPUT

Source No.	Key[a/] (State)	Dom/ NonDom[b/]	% Emission Reduction		Emissions (g/sec)		Estimated Added Annual Cost (000)
			SO_x	Particulate	SO_x	Particulate	
2	111	D	0	0	1,581	32.22	$ 0
	211	D	90	100	158.2	0.1611	3,796
	121	D	0	20	1,581	25.78	116.5
	131	D	0	30	1,581	22.55	169.1
	141	D	0	40	1,581	19.33	222.8
	151	D	0	98	1,581	0.6444	383.9
	161	D	0	99	1,581	0.3222	407.8
	171	D	0	100	1,581	0.1611	429.0
	112	D	19	0	1,282	32.22	630.0
	212	D	92	100	128.2	0.1611	4,426
	122	D	19	20	1,282	25.78	746.5
	132	D	19	30	1,282	22.55	799.1
	142	D	19	40	1,282	19.33	852.8
	152	D	19	98	1,282	0.6444	1,014
	162	D	19	99	1,282	0.3222	1,038
	172	D	19	100	1,282	0.1611	1,059
	113	D	38	0	973.7	32.22	1,470
	213	D	94	100	97.37	0.1611	5,266
	123	D	38	20	973.7	25.78	1,587
	133	D	38	30	973.7	22.55	1,639
	143	D	38	40	973.7	19.33	1,693
	153	D	38	98	973.7	0.6444	1,854
	163	D	38	99	973.7	0.3222	1,878
	173	D	38	100	973.7	0.1611	1,899
	114	D	58	0	659.2	32.22	3,360
	214	D	96	100	65.92	0.1611	7,156
	124	D	58	20	659.2	25.78	3,476
	134	D	58	30	659.2	22.55	3,529
	144	D	58	40	659.2	19.33	3,583
	154	D	58	98	659.2	0.6444	3,744
	164	D	58	99	659.2	0.3222	3,768
	174	D	58	100	659.2	0.1611	3,789
	115	N	79	0	333.5	32.22	5,250
	215	D	98	100	33.35	0.1611	9,046
	125	N	79	20	333.5	25.78	5,367
	135	N	79	30	333.5	22.55	5,419
	145	N	79	40	333.5	19.33	5,473
	155	N	79	98	333.5	0.6444	5,634
	165	N	79	99	333.5	0.3222	5,658
	175	N	79	100	333.5	0.1611	5,679

EXHIBIT V-4 - CONTINUED

SORT PROGRAM OUTPUT

Source No.	Key[a] (State)	Dom/ NonDom[b]	% Emission Reduction		Emissions (g/sec)		Estimated Added Annual Cost (000)
			SO_x	Particulate	SO_x	Particulate	
5	1111	D	0	0	15.06	0.3100	0
	2111	D	100	100	0	0	209.9
	1211	D	99	63	0.1657	0.1159	49.50
	1311	N	100	66	0.01506	0.1045	351.6
	1121	D	0	20	15.06	0.2480	1.400
	1131	D	0	30	15.06	0.2170	2.000
	1141	D	0	40	15.06	0.1860	2.600
	1112	D	19	0	12.21	0.3100	4.000
	1122	D	19	20	12.21	0.2480	5.400
	1132	D	19	30	12.21	0.2170	6.000
	1142	D	19	40	12.21	0.1860	6.600
	1113	D	38	0	9.227	0.3100	8.000
	1123	D	38	20	9.277	0.2480	9.400
	1133	D	38	30	9.277	0.2170	10.00
	1143	D	38	40	9.277	0.1860	10.60
	1114	D	58	0	6.280	0.3100	26.00
	1124	D	58	20	6.280	0.2480	27.40
	1134	D	58	30	6.280	0.2170	28.00
	1144	D	58	40	6.280	0.1860	28.60
	1115	D	79	0	3.178	0.3100	40.00
	1125	D	79	20	3.178	0.2480	41.40
	1135	D	79	30	3.178	0.2170	42.00
	1145	D	79	40	3.178	0.1860	42.60
9	1	D	0	0	9.380	592.4	0
	2	D	0	50	9.380	296.2	60.40
	3	D	0	78	9.380	130.3	72.20
	4	D	0	95	9.380	23.69	121.9
	5	D	0	96	9.380	29.62	78.70
	6	D	0	99	9.380	5.924	137.0

---

[a] The key references technology number and level. The control state must be read with Exhibit V-3, as follows:

```
Key:          2 1 3 1
              ↑ | ↑ ↑
              | | | └technology 1, level 1
technology 4,─┘ | technology 2, level 3
  level 2       technology 3, level 1
```

[b] A state is non-dominant if there exists at least one other state which emits less of each pollutant and costs less.

EXHIBIT V-5

DESCRIPTION OF EMISSION CONTROL ALTERNATIVES FOR UNCONTROLLED SOURCES

Source Model	Alternative	Method Used to Reach Reduction	Estimated Percentage Reduction in Emissions SO_x	Particulate
1 Power Plant (Coal 800 MW)	1	Install mechanical collector in series with an electrostatic precipitator.	- %	98.0%
	2	Substitute 1.5% sulfur coal for present 2.0% and install mechanical collector in series with an electrostatic precipitator.	25.0	99.5
	3	Switch to 2.0% sulfur residual oil from present 2.0% sulfur coal.	27.0	92.0
	4	Switch to 1.5% sulfur residual oil from present 2.0% sulfur coal.	45.0	92.0
	5	Install SO_2 stack gas cleaning equipment.	90.0	99.5
2 Power Plant (Residual Oil 800 MW)	1	Substitute 2.0% sulfur residual oil for present 2.5% sulfur residual oil.	19.0	-
	2	Substitute 1.5% sulfur residual oil for present 2.5% sulfur residual oil.	38.0	-
	3	Substitute 1.0% sulfur residual oil for present 2.5% sulfur residual oil.	58.0	-
	4	Substitute 0.5% sulfur residual oil for present 2.5% sulfur residual oil.	79.0	-

Exhibit V-5, cont'd

Source Model	Alternative	Method Used to Reach Reduction	Estimated Percentage Reduction in Emissions SO_x	Estimated Percentage Reduction in Emissions Particulate
3 Power Plant (Coal 200 MW)	1	Install a mechanical collector in series with an electrostatic precipitator.	- %	98.0%
	2	Substitute 1.5% sulfur coal for present 2.0%, and install a mechanical collector in series with an electrostatic precipitator.	25.0	98.0
	3	Substitute 1.0% sulfur coal for present 2.0%, and install a mechanical collector in series with an electrostatic precipitator.	50.0	99.5
	4	Switch to 1.0% sulfur residual oil from present 2.0% sulfur coal.	63.0	99.0
	5	Switch to natural gas on a firm basis from present 2.0% sulfur coal.	99.9	99.7
4 Stationary Combustion (Coal 100 x 10^9 Btu)	1	Substitute 1.5% sulfur coal for present 2.0%.	25.0	6.0
	2	Switch to 1.5% sulfur residual oil from present 2.0% sulfur coal.	45.0	98.0
	3	Switch to 0.5% sulfur residual oil from present 2.0% sulfur coal.	81.0	98.0
	4	Switch to natural gas on an interruptible basis from 2.0% sulfur coal.	99.0	99.5
	5	Switch to natural gas on a firm basis from 2.0% sulfur coal.	99.9	99.6

Exhibit V-5, cont'd

Source Model	Alternative	Method Used to Reach Reduction	Estimated Percentage Reduction in Emissions	
			SO_x	Particulate
5 Stationary Combustion (Residual Oil 400×10^9 Btu)	1	Substitute 2.0% sulfur residual oil for present 2.5%.	19.0%	- %
	2	Substitute 1.5% sulfur residual oil for present 2.5%.	38.0	-
	3	Substitute 0.5% sulfur residual oil for present 2.5%.	79.0	-
	4	Switch to natural gas on an interruptible basis from present 2.5% sulfur residual oil.	99.0	63.0
	5	Terminate own generation of electric power, and purchase electric power from a utility.	100.0	100.0
6 Stationary Combustion (Residual Oil 50×10^9 Btu)	1	Substitute 2.0% sulfur residual oil for present 2.5%.	19.0	-
	2	Substitute 1.5% sulfur residual oil for present 2.5%.	38.0	-
	3	Substitute 0.5% sulfur residual oil for present 2.5%.	79.0	-
	4	Switch to natural gas on an interruptible basis from 2.5% sulfur residual oil.	99.0	71.0
	5	Switch to natural gas on a firm basis from 2.5% sulfur residual oil.	99.9	76.0

///

Exhibit V-5, cont'd

Source Model	Alternative	Method Used to Reach Reduction	Estimated Percentage Reduction in Emissions SOx	Estimated Percentage Reduction in Emissions Particulate
7 Stationary Combustion (Coal 200 x 10^9 Btu)	1	Switch to 2.5% residual oil from present 2.0% coal.	11.0%	99.0%
	2	Switch to 1.5% residual oil from present 2.0% coal.	45.0	99.0
	3	Switch to 0.5% residual oil from present 2.0% coal.	81.0	99.0
	4	Switch to natural gas on an interruptible basis from present 2.0% coal.	99.9	97.0
	5	Switch to natural gas on a firm basis from present 2.0% coal.	99.9	99.6
8 Stationary Combustion (Residual Oil 300 x 10^9 Btu)	1	Substitute 2.0% sulfur residual oil for present 2.5%.	19.0	-
	2	Substitute 1.5% sulfur residual oil for present 2.5%.	38.0	-
	3	Substitute 0.5% sulfur residual oil for present 2.5%.	79.0	-
	4	Switch to natural gas on an interruptible basis from present 2.5% sulfur residual oil.	99.0	61.0
	5	Switch to natural gas on a firm basis from present 2.5% sulfur residual oil.	99.9	64.0

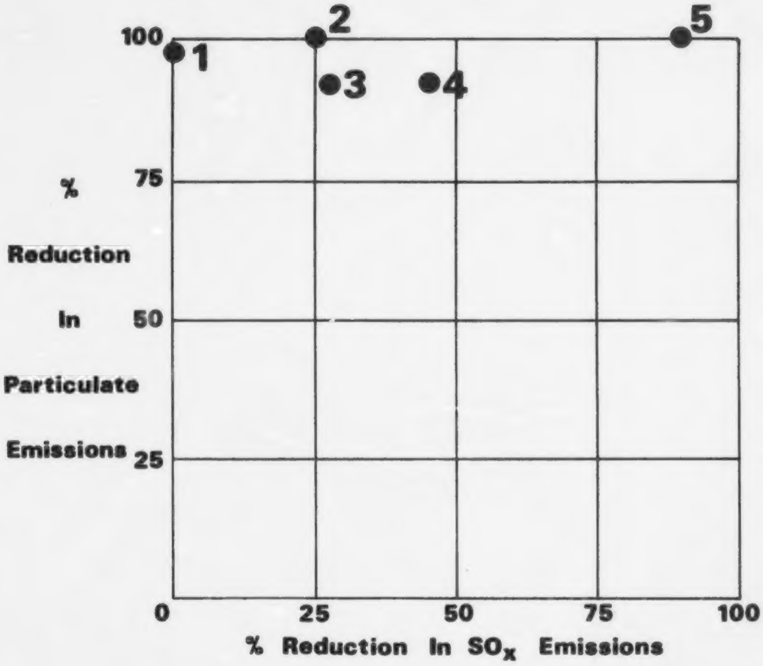
Exhibit V-5, cont'd

Source Model	Alternative	Method Used to Reach Reduction	Estimated Percentage Reduction in Emissions SO_x	 Particulate
9 Municipal Incinerator (500 ton/day)	1	Install a baffled spray chamber.	- %	50.0%
	2	Install a baffled spray chamber in series with a mechanical collector.	-	78.0
	3	Install a baffled spray chamber in series with an electrostatic precipitator.	-	95.0
	4	Install a wet scrubber.	-	96.0
	5	Install a baffled spray chamber in series with a fabric filter.	-	99.0

EXHIBIT V-6

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 1: POWER PLANT (COAL 800 MW)



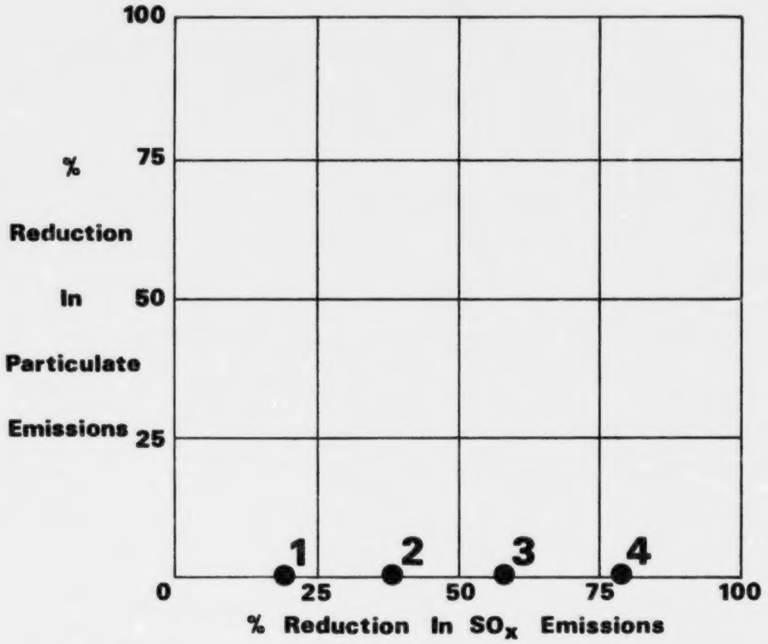
Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ 139	$ 369	$ 741
2	441	854	1482
3	847	1323	1918
4	1411	2205	3197
5	1299	3781	7086

114

EXHIBIT V-7

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 2: POWER PLANT (RESIDUAL OIL 800 MW)

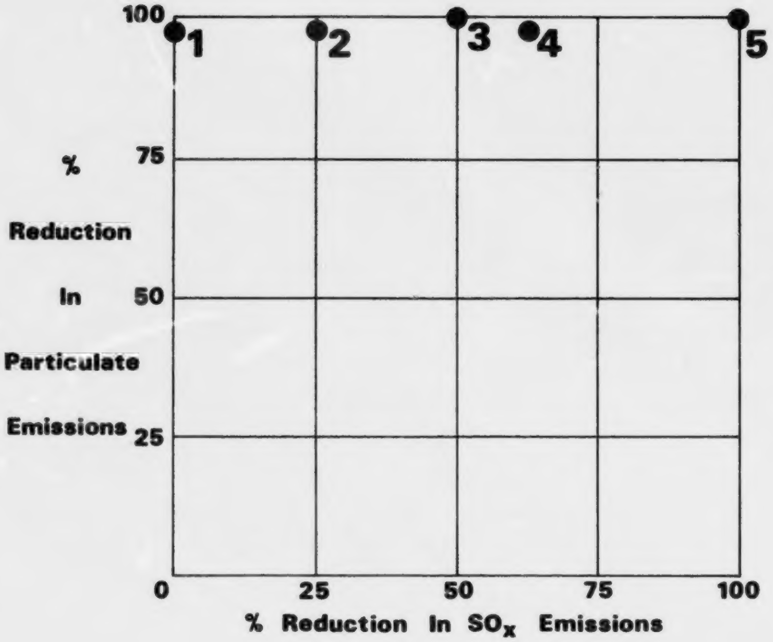


Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ 403	$ 630	$ 914
2	941	1470	2132
3	2150	3360	4872
4	3360	5250	7613
5			

EXHIBIT V-8

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 3: POWER PLANT (COAL 200 MW)



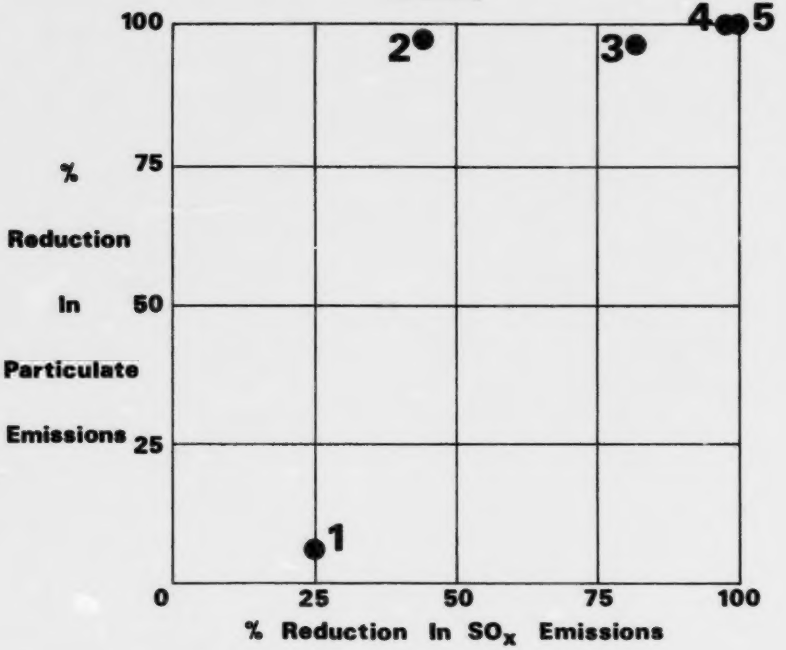
Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ 46	$ 117	$ 241
2	117	228	402
3	622	1021	1568
4	675	1055	1529
5	710	1110	1610

116

EXHIBIT V-9

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 4: STATIONARY COMBUSTION (COAL 100 x 10^9 BTU)

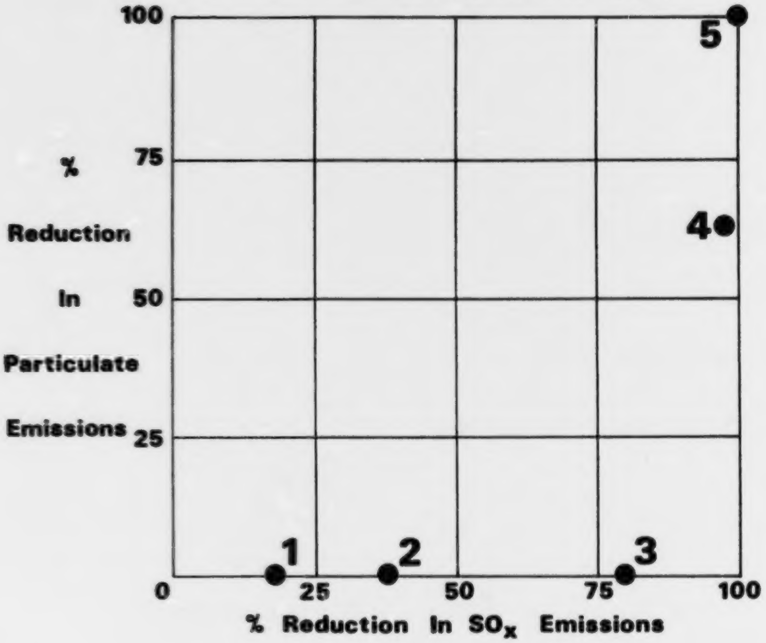


Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ 1	$ 1	$ 2
2	5	7	9
3	10	15	21
4	15	22	31
5	59	92	132

EXHIBIT V-10

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 5: STATIONARY COMBUSTION (RESIDUAL OIL 400×10^9 BTU)



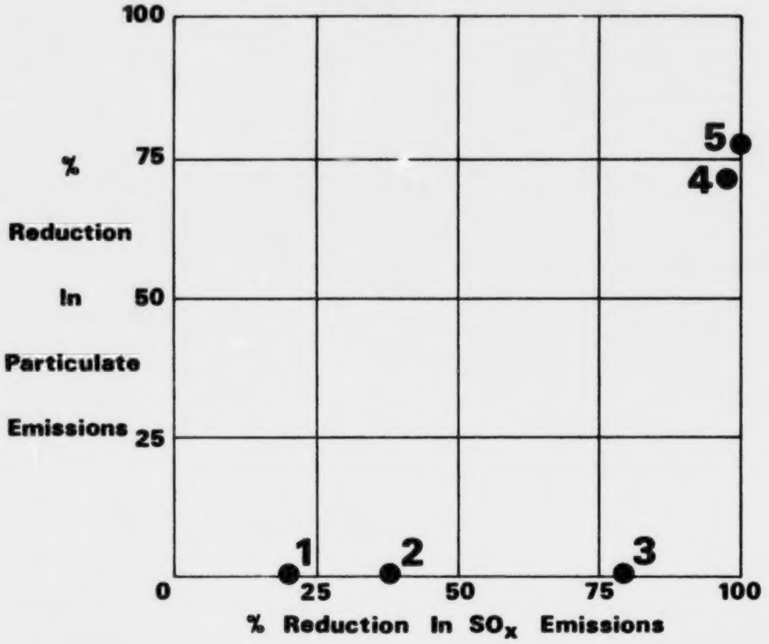
Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ 3	$ 4	$ 6
2	5	8	12
3	26	40	58
4	33	50	70
5	134	210	304

118

EXHIBIT V-11

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 6: STATIONARY COMBUSTION (RESIDUAL OIL 50 x 10^9 BTU)



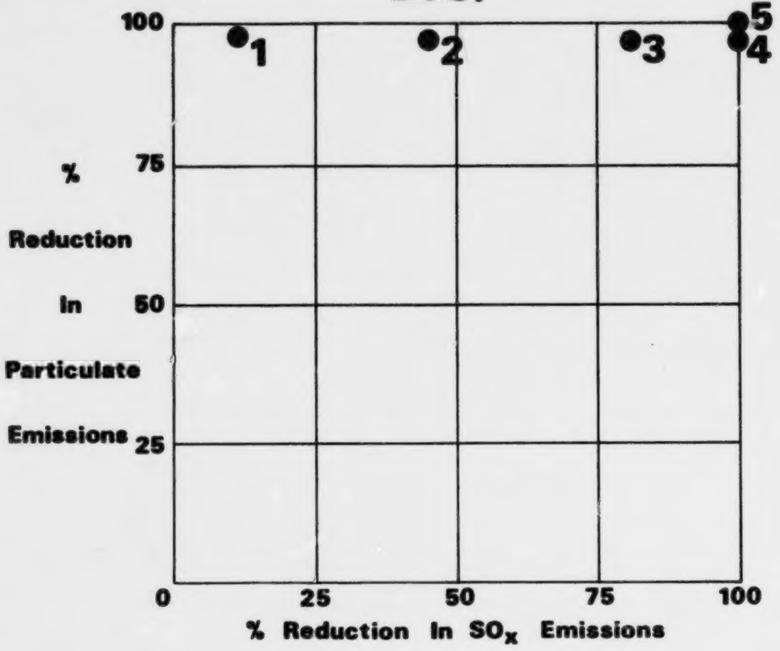
Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ 1	$ 1	$ 1
2	1	2	3
3	4	6	9
4	14	21	29
5	26	40	58

119

EXHIBIT V-12

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 7: STATIONARY COMBUSTION (COAL 200×10^9 BTU)



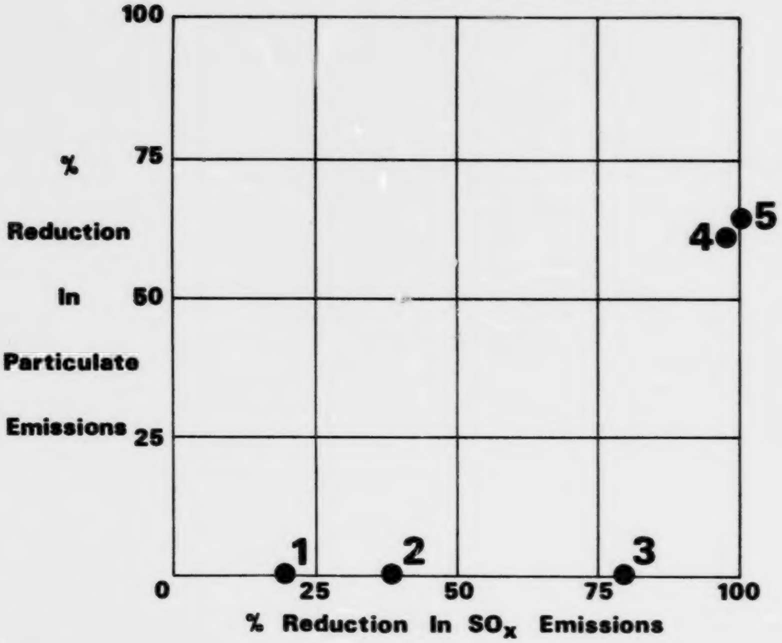
Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ -15	$ -5	$ 7
2	- 6	2	11
3	16	20	24
4	43	62	85
5	95	144	204

120

EXHIBIT V-13

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 8: STATIONARY COMBUSTION (RESIDUAL OIL 300×10^9 BTU)



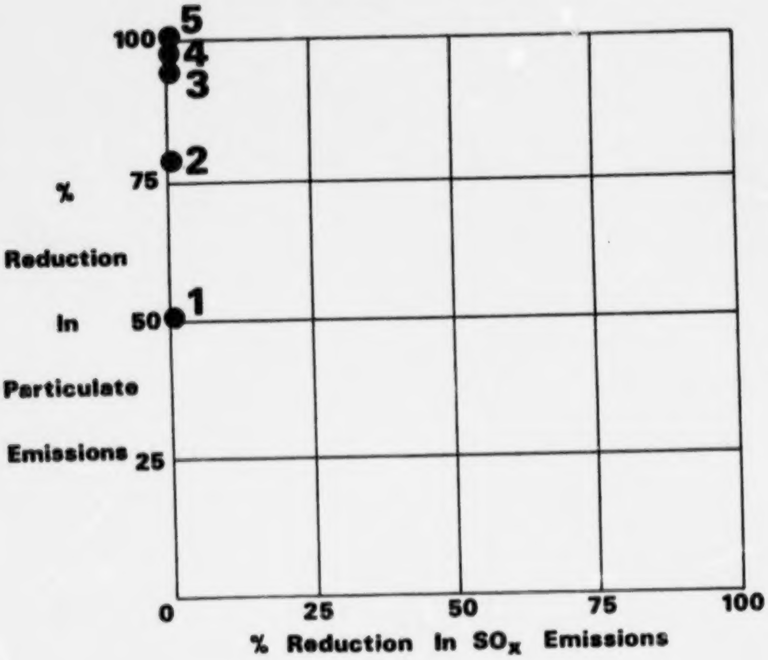
Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ 3	$ 5	$ 7
2	7	11	15
3	24	38	54
4	72	109	154
5	153	235	337

121

EXHIBIT V-14

ESTIMATED ANNUAL COSTS OF SO_x AND PARTICULATE EMISSION REDUCTION ALTERNATIVES

Source Model 9: MUNICIPAL INCINERATOR (500 TON/DAY)



Alternative Number	LOW ESTIMATE (000)	Estimated Annual Cost (000)	HIGH ESTIMATE (000)
1	$ 21	$ 60	$ 113
2	25	72	137
3	30	79	159
4	42	122	229
5	50	137	270

122

VI. KANSAS CITY STUDY

The results of this study for the National Air Pollution Control Administration (NAPCA) were presented in a summary report to the Kansas City, Kansas-Kansas City, Missouri Air Pollution Abatement Conference in May 1968 and later published by Ernst & Ernst in comprehensive detail in "A Cost-Effectiveness Study of Air Pollution Abatement in the Greater Kansas City Area," July 1969. As the methodology, study approach, and computer programs were the same as those used in the Washington, D. C. study, the reader is referred to Chapter IV of this report for a detailed discussion of the analyses.

OBJECTIVES

This study had two principal objectives:

(1) To compare the total annual cost of stipulated abatement strategies for achieving certain air quality levels in the Greater Kansas City Area

(2) To compare the cost of abatement to various classes of emission sources under the strategies. The strategies studied are

  (a) Maximum Abatement: effecting the greatest possible reduction of sulfur oxides (SO_x) and suspended particulate (SP)

  (b) Least Cost: the least cost combination of emission controls for all sources which achieves selected air quality levels for SO_x and SP at the least total cost to the whole area

  (c) Equiproportional: requiring all sources to reduce particulate emissions in concert with all other sources successively by at least 20, 40, 60, 80, and maximum percent of its base emissions.

  (d) Fuel Sulfur Restriction: restricting sulfur content of fossil fuels to 2 percent by weight or less

The study was confirmed to stationary sources of SO_x and SP. There are 129 major emission sources (sites that emit more than 100 tons a year of a single pollutant) in the area; the several thousand small sources were aggregated in this study, and their emissions apportioned on a fuel use or activity basis by census tract over a coordinate location grid. The same computer-assisted meteorological model used in the previous studies provided the average annual concentration of the two pollutants in the Greater Kansas City Area. The computer programs, used earlier in the Washington, D. C. study, combined compatible control technologies for each source to form control states, selected the most efficient states, and estimated annual costs for each of the four strategies for areawide abatement. This study did not consider the cost to the Federal or local governments of implementing and enforcing any of the abatement strategies simulated.

INPUTS

The types of inputs required for this study were the same as for the Washington, D. C. study (see page IV-2).

Exhibit VI-1 gives the classes of point and area emissions sources of particulate and SO_x found in the Greater Kansas City Area and their percentage contribution to total emissions. These sources emit particulate and SO_x primarily from the combustion of fuels for space heating and power generation or from refuse incineration. About 49,500 tons of particulate and 120,000 tons of SO_x are emitted each year in the area from stationary sources. The remainder is emitted by mobile sources, which are treated as irreducible background pollution in this study.

ANALYSIS

Meteorological Analysis

Application again of the meteorological model used in the previous studies along with the Kansas City Area's average annual winds, both provided by NAPCA, allowed the surveyed point and area emissions to be translated into ground level concentrations of pollutants at the receptor points. Contributing sources of pollution outside the area were not taken into account. While particulate of various dimensions is emitted from sources, only respirable particulate (i.e., suspended particulate, SP) was calculated at the receptor points. Suspended particulates were assumed to be less than 10 microns and to constitute a constant 100 percent of the total particulate emitted by each point and area source.

The results of this analysis are shown in Exhibit VI-2, which illustrates the pre-abatement pollution levels of suspended particulate in the area.

The black contours, called iso-intensity lines, connect points of equal annual average (arithmetic mean) concentrations of suspended particulate in micrograms per cubic meter ($\mu gm/m^3$). The concentrations

124

EXHIBIT VI-1

ESTIMATED EMISSIONS SO_x AND PARTICULATE FROM POINT AND AREA SOURCES IN 1967 [a]

Emission Source Class	Emissions			
	Particulate		SO_x	
	Tons/yr.	% of Total	Tons/yr.	% of Total
Point Source Classes [b]				
Power plants	6,031	10.2	64,508	51.9
Asphalt batch plants	281	0.5	-0-	-
Cement plants	5,445	9.2	-0-	-
Ferrous foundries	1,840	3.1	72	0.06
Grain handling & storage	4,521	7.6	648	0.5
Chemicals-petro refineries	1,977	3.3	37,664	30.3
Fiberglass plants	2,029	3.4	92	0.07
Nonferrous foundries	1,969	3.3	36	0.03
Auto manufacturers	552	0.9	170	0.1
Miscellaneous	2,989	5.0	4,173	3.4
Open burning dumps	12,554	21.2	314	0.3
Total point source emissions	40,188	67.7	107,677	86.6
Aggregated Area Sources [c]				
Coal users	1,754	3.0	9,425	7.6
Oil users (distil. & used)	515	0.9	2,973	2.4
Natural gas users	1,008	1.7	-0-	-
Incineration	229	0.4	-0-	-
Process losses	2,205	3.7	-0-	-
Open burning	3,604	6.1	85	0.07
Total Stationary Emissions	49,503	83.6	120,160	96.6
Mobile emissions (auto, truck, railroad, aircraft, barge) [d]	9,716	16.4	4.213	3.4
Total Emissions	59,219		124,373	

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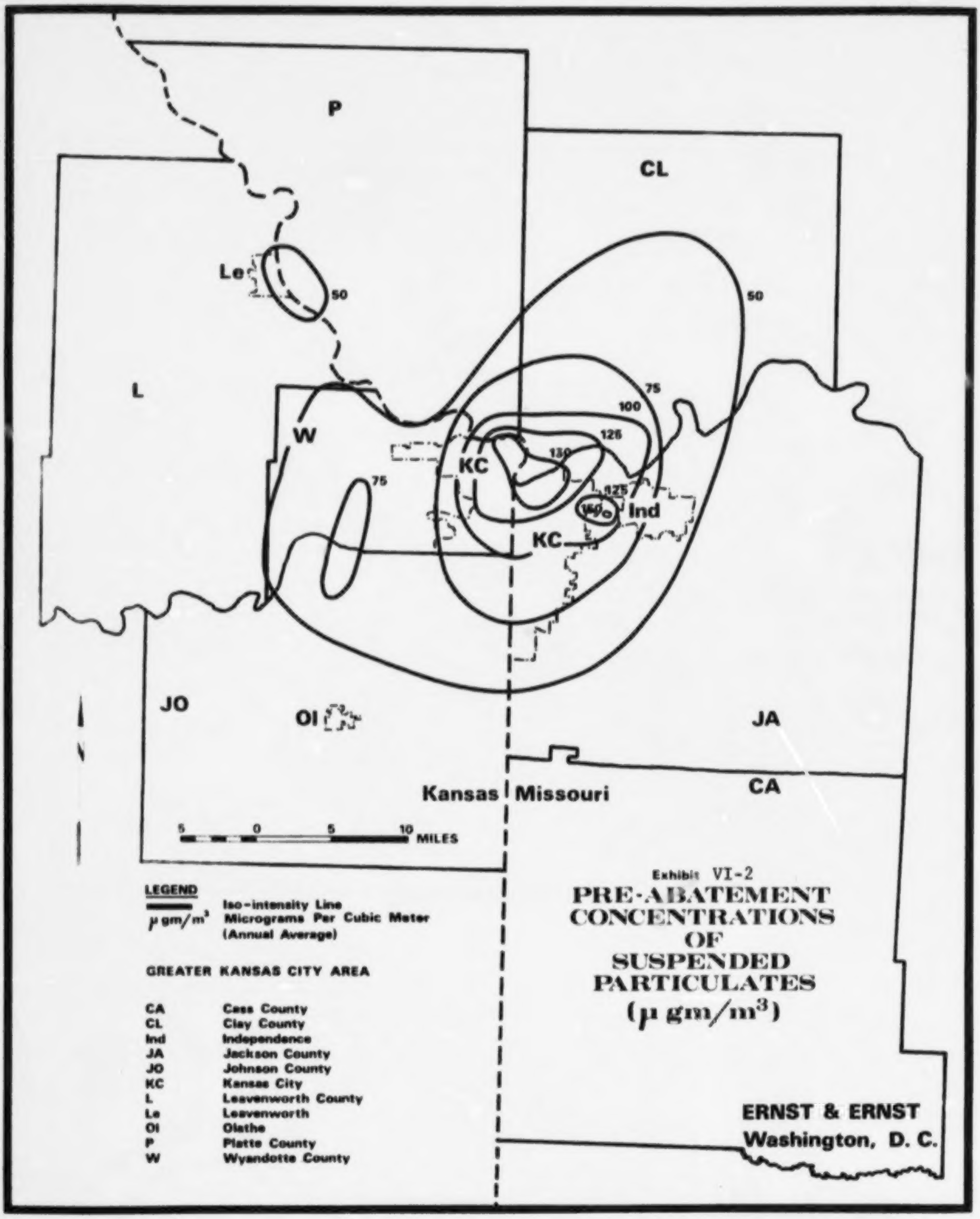
[a] Public Health Service

[b] A "point source" emits more than 100 tons a year of a single pollutant.

[c] An "area source" is an aggregation of sources each of which emits less than 100 tons a year of a single pollutant.

[d] These are areas sources for which no controls were stipulated.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Missouri
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MILES
ERNST & ERNST
Washington, D. C.

Exhibit VI-2

PRE-ABATEMENT CONCENTRATIONS OF SUSPENDED PARTICULATES (μ gm/m^3)

LEGEND

—	Iso-intensity Line
μ gm/m^3	Micrograms Per Cubic Meter (Annual Average)

GREATER KANSAS CITY AREA

CA	Cass County
CL	Clay County
Ind	Independence
JA	Jackson County
JO	Johnson County
KC	Kansas City
L	Leavenworth County
Le	Leavenworth
Ol	Olathe
P	Platte County
W	Wyandotte County

contributed by all sources to each receptor point were added, and the iso-intensity lines then interpolated. The estimated annual average concentrations of suspended particulates shown by these iso-intensity lines range from 50 $\mu gm/m^3$ to 150 $\mu gm/m^3$. The estimated concentrations of SO_x are shown in Exhibit VI-3. These concentrations range from negligible amounts to 0.040 parts per million (ppm), as an annual average.

Abatement Analysis

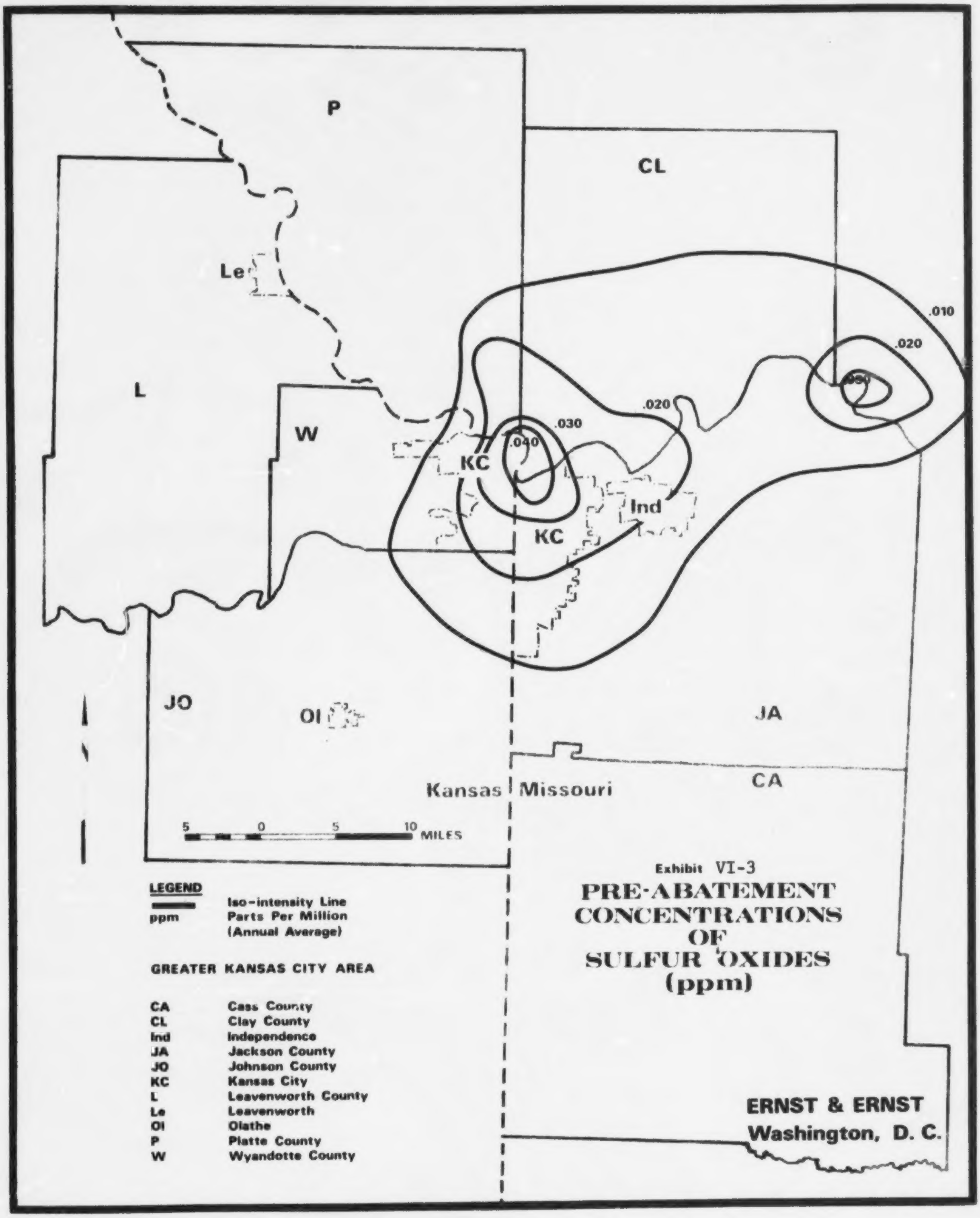
As in the Washington, D. C. study, the emission control technologies considered in this study are (1) fuel substitution and fuel switching, (2) the installation of mechanical collection devices, and (3) the use of sanitary landfill. In addition to these technologies, sulfur recovery processes and afterburners were considered as possible controls for refinery gas and combustible effluents. These two technologies are discussed below.

Sulfur Recovery - Process and combustion sulfur oxides emissions are controlled in petroleum refineries by a sulfur recovery process. Refinery gases contain hydrogen sulfide (H_2S). The first step in the recovery process is to oxidize part of the H_2S to SO_2. Then the SO_2 and the remaining H_2S are combined to form elemental sulfur and water.

Afterburner - An afterburner can be used to control emissions whenever equipment releases combustible aerosols, gases, or vapors into the air. Two types of afterburners are in current use: direct fired and catalytic. Catalytic afterburners are used where temperatures are too low for burning without a catalyst. An afterburner consists of a combustion chamber, gas burner, burner controls, and temperature indicator.

These control technologies were selected in conjunction with NAPCA. The technologies are based on conditions as they existed at the time the emissions inventory was prepared by NAPCA during February to July 1967.

Emission control technologies excluded from the analysis are nuclear power plants to replace present steam electric generating stations; construction of higher smoke stacks; relocation or closing down of any source, except incinerators and open-burning areas; improved maintenance of facilities; industrial process changes; use of liquified natural gas, gasified coal, fuel cells, or exotic fuels; and changing land use or zoning policies. Nor is the time phasing of controls considered; that is, it is assumed that all controls are applied instantaneously and all sources are controlled concurrently. Some or all of these may be both practical and available means of improving air quality in the Greater Kansas City Area, but their consideration in this study was not possible.


P
CL
Le
L
W
KC
KC
Ind
.010
.020
.020
.030
.040
JO
Ol
JA
CA
Kansas
Missouri
5
0
5
10
MILES

LEGEND

▬	Iso-intensity Line
ppm	Parts Per Million (Annual Average)

GREATER KANSAS CITY AREA

CA	Cass County
CL	Clay County
Ind	Independence
JA	Jackson County
JO	Johnson County
KC	Kansas City
L	Leavenworth County
Le	Leavenworth
Ol	Olathe
P	Platte County
W	Wyandotte County

Exhibit VI-3

PRE-ABATEMENT CONCENTRATIONS OF SULFUR OXIDES (ppm)

ERNST & ERNST
Washington, D. C.

128

Exhibits IV-9 and IV-10 in Chapter IV show the emission rates of the various types and sizes of stationary combustion sources and incinerators that were used as input to this model. Exhibit IV-7 illustrates the emission control technologies assumed to be practical and available to major stationary combustion sources using coal or oil for the generation of heat or power.

The costs given were obtained from a number of sources. Foster Associates, Inc., economic consultants, provided fuel costs. Other costs were obtained from manufacturers of equipment, from published sources, and from conversations with government and industry experts in the field of air pollution abatement. A comprehensive report of these costs is given in Chapter V of the report mentioned earlier, "A Cost-Effectiveness Study of Air Pollution in the Greater Kansas City Area."

The emissions by source and the costs and effectiveness of control technologies were input to the SORT program (see Exhibit IV-2). A detailed example of the use of the SORT program is given in Chapter V. The program listings and logic diagrams are shown in Appendix D.

Final Analysis

The SORTCON and INTCODE Programs (see Appendix D) were again used in this study to select the most efficient emission control state for each source in conformance with the strategy to be simulated and then compute the resultant concentrations and costs.

COST-EFFECTIVENESS RESULTS

The cost and effectiveness results of the simulations of the stipulated strategies are plotted in Exhibit VI-4. The vertical axis is the estimated annual cost in millions of dollars; the horizontal axis is the predicted maximum annual average concentration of suspended particulates at any point in the Greater Kansas City Area.

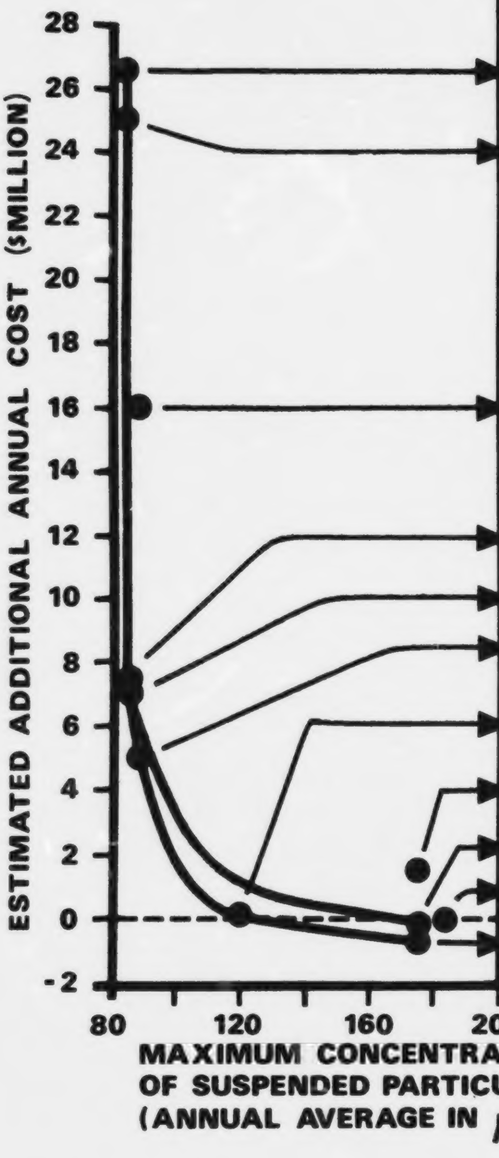
The top-most point in the exhibit locates the maximum abatement strategy results. Maximum abatement requires the use of natural gas for combustion, mechanical controls in process emissions, and sanitary landfill for solid waste disposal.

The lowest point locates the lowest cost strategy. The lowest cost strategy results in an estimated total cost reduction of over $700,000 from the base conditions but does not change the pollution values significantly. This result is explained by the fact that some sources can apparently effect operating cost reductions by buying fuels which are cheaper than those now being used and at least as low in sulfur and ash content. A similar result was obtained in the Washington, D. C. study (Chapter IV).

The curve connecting the cost of the maximum abatement strategy to the lowest cost contains all of the least cost solutions for reducing the maximum concentration of suspended particulates without deliberately

EXHIBIT VI-4

COMPARISON OF SIMULATED ABATEMENT STRATEGIES FOR THE GREATER KANSAS CITY AREA



STRATEGY	MAXIMUM CONCENTRATION		% EMISSION REDUCTION	
	μgm/m^3	ppm	SP	SO$_X$
MAXIMUM CONTROL	85	0.015	69	81
MAXIMUM PARTIC. CONTROL	85	0.030	69	48
EP PARTIC. REDUC. ≥ 20%	89	0.035	59	13
LEAST COST	86	0.023	66	42
"	86	0.040	68	7
"	89	0.040	59	7
"	120	0.040	22	5
2% SULFUR FUELS	175	0.035	10	38
LEAST COST	177	0.023	5	40
BASE	184	0.046	0	0
LOWEST COST	177	0.040	5	5

controlling sulfur oxides. The curve which merges with it connects all the least cost strategies for reducing the maximum concentration of suspended particulates while requiring that the initial maximum concentration of sulfur oxides, 0.046 ppm, be reduced by half to 0.023. These least cost curves are shown as smooth curves for convenience; they are actually made up of a large number of discrete steps, since there are only a finite number of possible control states.

The least cost strategy chooses the set of control states which achieves a stated objective for the least total annual cost incurred within the community. For example, with no deliberate sulfur oxides control a simulated reduction of the initial maximum concentration of suspended particulates from 184 μgms/m^3 to 120 μgms/m^3 can be achieved with a 22 percent reduction in particulate emission for almost no net increase in the estimated annual cost. Reduction to 89 μgms/m^3 can be achieved for an estimated cost of $5 million annually with a 59 percent reduction in emissions. Reduction to 86 μgms/m^3 can be achieved with a 68 percent reduction in emissions for an estimated $7 million annually. A bonus reduction of the maximum concentration of sulfur oxides to 0.040 ppm is also realized. For another $500,000 annually the maximum sulfur oxides concentration can be reduced to 0.023 ppm with a 42 percent reduction in SO_x emissions.

Comparing these least cost solutions to the maximum abatement strategy reveals that after a certain level great increases in cost bring about small emission reductions. The results of at least a 20 percent reduction of particulate by the equiproportional particulate reduction strategy show that the maximum concentration of suspended particulate is reduced to 80 μgms/m^3 with a 59 percent reduction in total annual particulate emissions for an estimated cost of over $16 million annually. The corresponding least cost solution has an estimated annual cost only one-third of that. For an additional $9 million annually the maximum particulate control strategy effects only a 16 percent increase in particulate emission reduction over the first equiproportional step. This implies that in the computer simulation many sources went to maximum control in the first step.

The simulated equiproportional emission reductions of 40, 60, or 80 percent do not generate further significant reductions either in concentrations or in total emissions; the only significant change is increased cost.

The estimated cost of restricting the sulfur content of fuels to 2 percent by weight or less is $3.5 million annually in increased fuel costs. This strategy reduces the sulfur oxides peak concentration to 0.035 ppm and effects a 38 percent reduction in the total tonnage of sulfur oxides emitted. At the same time particulate emissions are reduced 10 percent. Notice that one of the least cost solutions halves the peak SO_x concentration and reduces the sulfur oxides emissions by 40 percent with no overall increases in annual cost.

VII. CONCLUSIONS AND IMPLICATIONS

The principal characteristics of the five studies discussed in the previous chapters are compared in the tables in Appendix E. Those tables and the details of the methods and results of the studies leave little question that simulation can accommodate at least the significant relationships characterizing real urban air pollution situations. In fact, the only limitation on the degree of complexity and detail which can be simulated is the time and money required to develop appropriately detailed inputs, especially meteorological factors, costs, plant characteristics, and equipment descriptions (collection efficiencies, operating limitations, etc.). This being the case, the use of simulation and cost-effectiveness techniques to analyze urban air pollution abatement alternatives can be a powerful tool for government, for industry, and for the public.

For government, these analytical techniques can be helpful in formulating both broad public pollution abatement policy alternatives and "pre-playing" detailed abatement implementation plans. In view of the scheduled requirements mandated by the Air Quality Act of 1967 for air quality standards and implementation plans within Federally-designated air quality control regions, the techniques discussed have an obvious utility in

- evaluating uniform and nonuniform emission standards within a region
- developing a priority list of sources having the greatest impact on air quality
- coordinating of regional, state, and local plans and requirements
- developing coherent time phasing of controls over a region so as to optimize the allocation of manpower and material resources
- informing the public of the effects and costs of air pollution and its control
- training control agency personnel in the use of decision aids and abatement planning

For industry, cost-effectiveness techniques can be useful both in selecting the least-cost, or near least-cost, emission controls from among a number of alternatives, and in determining area-wide least-cost, or near least-cost, strategies achieving mandated air quality standards.

For public clean air organizations, simulation can be a useful means of testing the feasibility of public policy proposals, such as new abatement codes, affecting air quality and emission standards, and enforcement.

Thus, these techniques can be useful to government, industry,

132

and public bodies in developing a more rational basis for action relative to any stipulated set of goals. This implies that these techniques can provide a consistent quantitative basis for resolving public policy conflicts concerning air pollution abatement goals and controls.

APPENDIX A

MET PROGRAM FLOW DIAGRAM AND LISTING

APPENDIX A

THE MET PROGRAM

The MET program is a computerized meteorological diffusion model developed by personnel of the Environment Sciences Administration and the Public Health Service for determining the concentration of a pollutant at any arbitrary receptor point per unit emission from each source point. The model is based on the generalized Gaussian diffusion equation [40] [41], which follows.

$$C = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\frac{1}{2}\left(\frac{Y^2}{\sigma_y^2} + \frac{H^2}{\sigma_z^2}\right)\right]$$

where:

C = pollutant concentration, grams per cubic meter

Q = pollutant emission rate, grams per second

$\bar{u}$ = wind speed, meters per second

H = effective height of source, meters

Y = horizontal distance from plume centerline, meters

σ_y = standard deviation of the distribution of pollutant concentrations in the horizontal direction, meters

σ_z = standard deviation of the distribution of pollutant concentrations in the vertical direction, meters

The values of σ_y and σ_z depend upon the atmospheric stability and the source-to-receptor distance measured along the centerline. The important meteorological factors that affect concentrations at particular points are wind speed, wind direction, and stability class. Over any time period, these occur in various combinations, and they were taken into account in the diffusion model by using a weighting factor that indicates the proportion of time in which each combination occurs during the prescribed time period. The wind-speed categories chosen are (in miles per hour) 1 to 3, 4 to 7, 8 to 12, 13 to 18, 19 to 24, and in excess of 25. A total of 16 wind directions were used, spaced around the compass at angles of 22 1/2°. Five stability classes were selected; the first four correspond to Pasquill's classes A to D,[42] while the fifth represents Pasquill's categories E and F grouped together. Calms were distributed in the lowest wind-speed category for the five stability classes and 16 wind directions in the same proportion as indicated by observed data.

Additional input consists of the grid coordinates of the emission source and all receptor points.

Exhibit A.2 presents a generalized layout of the program logic; Exhibit A.1 gives a listing of the program in FORTRAN IV language.

The factors ALWT and GRID are conversion constants. ALWT converts the grams-per-cubic-meter output of the basic equation into parts per million. The factor varies by the molecular weight of the pollutant involved. A list of some of these factors for common pollutants follows.

POLLUTANT	ALWT
SO_2	375.66
NO	801.06
NO_2	522.50
H_2S	705.40
CO	858.26
CO_2	546.23
NH_3	1411.63
Cl_2	399.02
HCl	659.17
HF	1201.39

The factor GRID is for converting into meters the units of the grid coordinates on which the source and receptors are located. One unit of a grid coordinate system times GRID equals a certain number of meters.

136

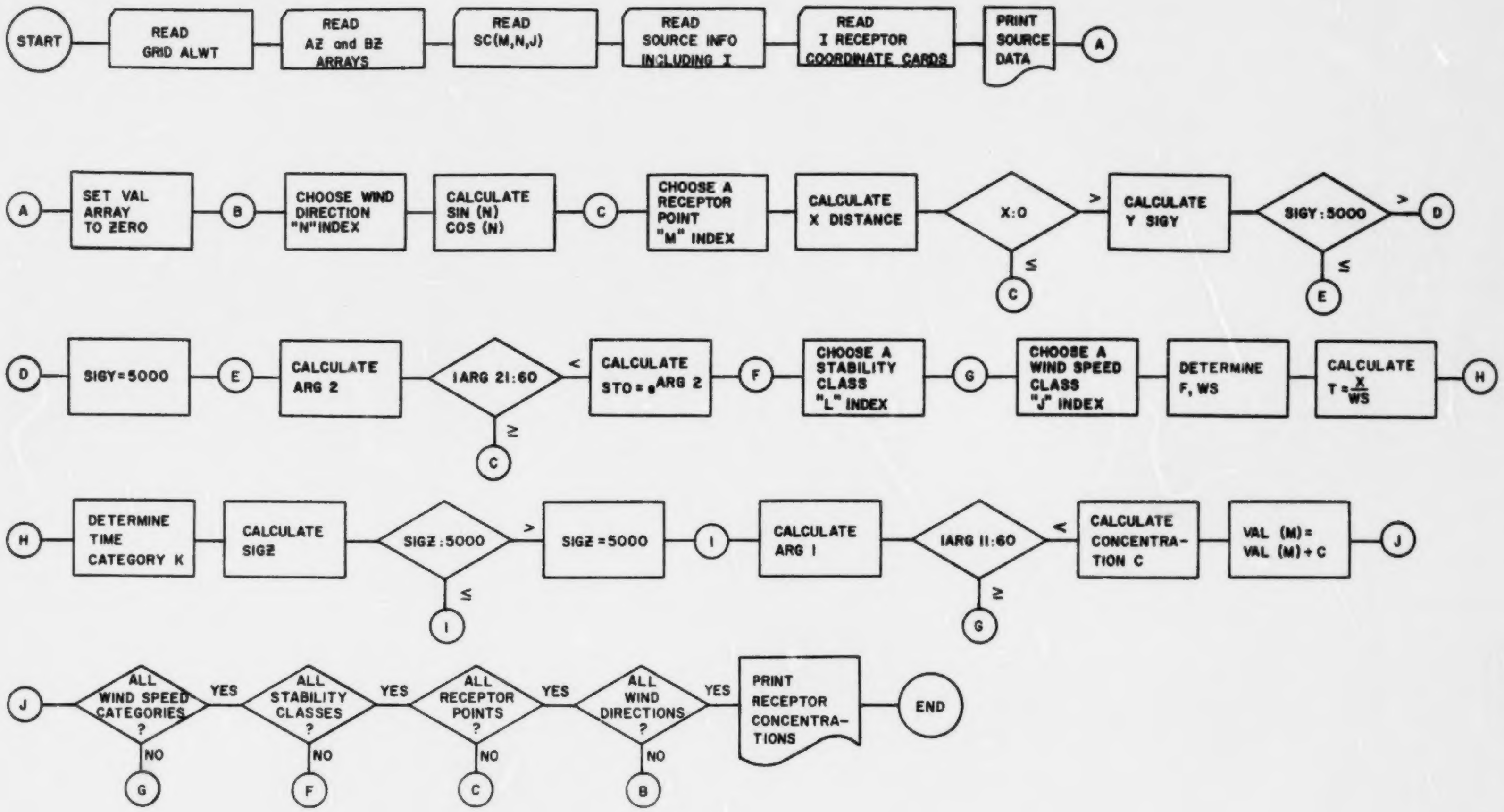
EXHIBIT A-1

METEOROLOGICAL DIFFUSION MODEL PROGRAM LISTING (FORTRAN IV)

```
      DIMENSION SC(5,16,6),AZ(6.5),BZ(6,5),REM(4)
      DIMENSION RHOR(50), RVER(50).VAL(50)
  1   FORMAT  (4X,6F11.5)
  2   FORMAT  (7X,6F7.5)
101   FORMAT (1H1/1HO,3X,6HSOURCE.  25X.2F8.1,8X,4A6)
102   FORMAT  (1HO,3X,27HEMISSION  RATE IN GRAMS/SEC.,F10.2/1HO)
103   FORMAT  (1HO,3X,22HSTACK  HEIGHT  IN METERS, 5X,F10.2)
104   FORMAT  (1HO,22X,26HCOORDINATES   VALUE IN PPM)
105   FORMAT  (1HO,20X,F6. 1,F8.1,E14.5)
106   FORMAT  (1X,2F4.1,F5.2,F6.2,4A6,12)
107   FORMAT  (1X,2F4.1)
 73   FORMAT  (2F10.5)
      READ(2,73)  GRID,  ALWT
      READ(2,1)  ((AZ(K,L), K=1,6), L=1.5)
      READ(2,1)  ((BZ(K,L), K=1,6), L=1,5)
      READ(2,2)   (((SC(M,N,J),J=1,6),N=1,16),M-1,5)
      READ(2,106)  SHOR,SVER,H,Q,REM(1),REM(2),REM(3),REM(4),I
      READ(2,107)  (RHOR(M),RVER(M), M=1,I)
      WRITE  (3,101)  SHOR,SVER,REM(1),REM(2),REM(3),REM(4)
      WRITE  (3,102) Q
      WRITE  (3,103) H
      WRITE  (3,104)
      DO  110 M=1,I
110   VAL(M) =  0.0
      DO 96  N=1.16
      B=N
      RAD=(B-1.)*(.3927)
      BSIN=SIN (RAD)
      BCOS=COS (RAD)
      DO  97  M=1,I
      X =  GRID*((RVER(M)-SVER)  *BCOS+(RHOR(M)-SHOR)*BSIN)
      IF(X) 97,97,4
  4   Y =  GRID*((RVER(M)-SVER) *BSIN-(RHOR(M)-SHOR)*BCOS)
      SIGY =  .157 * X
      IF  (SIGY-5000.)  36,36,35
 35   SIGY=5000.
 36   ARG2 = (-.5*Y*Y)/(SIGY*SIGY)
      IF  (ABS (ARG2) - 60.)32,97,97
 32   STO = EXP (ARG2)
      DO 98  L=1,5
      DO 99  J=1,6
      F  = SC(L,N,J)
      IF (F) 99,99,10
```

EXHIBIT A-2

METEOROLOGICAL DIFFUSION MODEL PROGRAM LOGIC


START
READ GRID ALWT
READ AZ and BZ ARRAYS
READ SC(M,N,J)
READ SOURCE INFO INCLUDING I
READ I RECEPTOR COORDINATE CARDS
PRINT SOURCE DATA
A
A
SET VAL ARRAY TO ZERO
B
CHOOSE WIND DIRECTION "N" INDEX
CALCULATE SIN (N) COS (N)
C
CHOOSE A RECEPTOR POINT "M" INDEX
CALCULATE X DISTANCE
X:0
>
≤
C
CALCULATE Y SIGY
SIGY:5000
>
D
≤
E
D
SIGY=5000
E
CALCULATE ARG 2
IARG 21:60
<
≥
C
CALCULATE STO = e^ARG 2
F
CHOOSE A STABILITY CLASS "L" INDEX
G
CHOOSE A WIND SPEED CLASS "J" INDEX
DETERMINE F, WS
CALCULATE T = X/WS
H
H
DETERMINE TIME CATEGORY K
CALCULATE SIGZ
SIGZ:5000
>
≤
I
SIGZ=5000
I
CALCULATE ARG I
IARG 11:60
<
≥
G
CALCULATE CONCENTRATION C
VAL (M) = VAL (M) + C
J
J
ALL WIND SPEED CATEGORIES ?
YES
NO
G
ALL STABILITY CLASSES ?
YES
NO
F
ALL RECEPTOR POINTS ?
YES
NO
C
ALL WIND DIRECTIONS ?
YES
NO
B
PRINT RECEPTOR CONCENTRATIONS
END

APPENDIX B

MODEL CITY II STUDY PROGRAM

APPENDIX B

MODEL CITY II STUDY PROGRAM

This appendix contains flow charts and program listings for the computer programs used in the Model City II Study. The program begins and ends in Phase I (main program). Phase I also determines the calling sequence of all other routines - Phase II through Phase VII, PCC, INIT, PLOT, SYMBOL, CHART, BOX, PLT 1 through PLT 7, SOLUTN, ENVLPE, LPUNCH, ENDPLT, and STOPPLOT. For each source Phase II computes the total private fixed and variable cost, and the total governmental fixed and variable costs for each technology at each operating level and allocates these costs to either waste-treatment, process change, or fuel substitution costs. Phase III is the phase in which all pre-abatement emission, concentration, and contribution computations are made for both SO_2 and particulates. In the Phase IV routine with the aid of the COST routine, the elemental cost curves for reduction of SO_2 emissions and reduction of human exposure to SO_2 are computed and printed for each source. Phases V, VI, and VII are almost identical in structure; each gives the aggregate private and government, fixed, and variable cost on the Phase's aggregate cost curve and allocates these costs to either waste-treatment, process change, or fuel substitution costs. The aggregate cost curves in Phases V, VI, and VII are the least cost curve for reduction of SO_2 emissions, the least cost curve for reduction of human exposure to SO_2 and the equiproportional curve for reduction of SO_2 emissions and for reduction of human exposure to SO_2 respectively. Each curve produced in Phases V, VI, and VII is plotted as well as being printed. Using the keys developed in Phases V and VII, computations in PCC produce aggregate cost curves for nominal particulate reduction of a maximum of five selected percent levels. PLT 1 through PLT 7 produce tables showing percent SO_2 reduction versus the least-cost emission reduction costs, the least-cost exposure reduction costs, and the aggregate equiproportional costs.

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```
      PROGRAM PHASE1
C
C     PHASE I
C
      DIMENSION MOM(20)
      COMMON/3/ ACCPFC(10),ACCPVC(10),ACCPPC(10),ACCPWC(10),ACCPSC(10),
     1          ACCTPC(10),ACCGFC(10),ACCGVC(10),ACCGPC(10),ACCGWC(10),
     2          ACCGSC(10),ACCTGC(10),ACCGTC(10),ACCPSR(10),ACCASR(10),
     3          ACCAER(10),ACCUSC(10),ACCMSC(10),ACCJEC(10),ACCHEC(10),
     4          ACCPPR(10),ACCAPR(10),ACCPER(10)
      COMMON/1/ ECCPFC(48,10),ECCPVC(48,10),ECCPWC(48,10),ECCPPC(48,10),
     1ECCPSC(48,10),ECCGFC(48,10),ECCGVC(48,10),ECCGWC(48,10),ECCGPC(48,
     210),ECCGSC(48,10),LEVECC(48,10,6),            ECCTGC(48,10),ECCG
     3TC(48,10),ECCPSR(48,10),ECCASR(48,10),ECCUSC(48,10),ECCMSC(48,10),
     4ECCPER(48,10),ECCAER(48,10),ECCUEC(48,10),ECCMEC(48,10),ECCPPR(48,
     510),ECCPST(48,10),ECCPET(48,10),ECCPPT(48,10)
      COMMON/5/ RUNAME(19),FIXINC(3),OPRINC(3),            NTECH(48),
     1           POP(48),REDLC(10),REDPT(5) ,ENAME(48,6),
     2 PART(48),
     3    TNAME(48,5,6),NOPLEV(48,5),SREDUC(48,5,8),PREDUC(48,5,8),
     4 FIXCST(48,5,8),OPRCST(48,5,8),NTYPE(48,5),NCODE(48,5),
     5              FOX(3),OPR(3),PFCOST(   5,8),PVCOST(   5,8),
     6 GFCOST(   5,8),GVCOST(   5,8),PWCOST(   5,8),PSCOST(   5,8),
     7 PPCOST(   5,8),GWCOST(   5,8),GSCOST(   5,8),GPCOST(   5,8),AB(5)
     8,EXPOSE(48),CONCEN(48),MBIG(5),CONBIG(5),XBIG(5),YBIG(5),PER(5)
      COMMON/9/ CLOWER(48,10),LEVE(48),                  NCUR(48),
     1          LOP(48,10,8),RCURVE(48,10),CCURVE(48,10),CLOW(48,10),
     2          LEVELP(48)
      COMMON NOGO(48,5,5),
     1       NCURVE(48), SCOEF(48,30), ECCTPC(48,10), ECCAPR(48,10),
     2       XRECEP(48), YRECEP(48), XSRC(48), YSRC(48), HEIGHT(48),
     3 GFACT(48), WIDTH(48), SQ2(48)
      COMMON/4/ SAC(5,10),INDCTR(48,5,10),RED(48,10)
      COMMON/2/ INILEV(48,5)
      COMMON/7/ DATA(12,2,7)
      COMMON/20/  ENAM(3),RUNAM(10),PERCENTS(7)
      DIMENSION CONCST(48,10)
      EQUIVALENCE (ECCMEC,CONCST)
   12 FORMAT (32X,6F4,1,I4,I1,F4,1,I2,I1,I4)
   15 FORMAT (1X,2F4,1,15X,F4,0)
   13 FORMAT (10F4,1)
   14 FORMAT (9F4,1)
   21 FORMAT (1X,2F4,1,F5,2,F6,2,6A4,2X,2F10,5,F6,2,I1)
   32 FORMAT (2F4,1,2F6,1)
      WRITE(3,850)
  850 FORMAT (*1*,50X,*INPUT DATA*/)
      READ ( 5,11) (RUNAME(K),K=1,19)
   11 FORMAT (19A4)
      WRITE(3,851) (RUNAME(K),K=1,19)
  851 FORMAT (10X,*RUN NAME  =*,2X,19A4//)
      ENCODE(76,995,RUNAM(1))(RUNAME(K),K=1,19)
  995 FORMAT (19A4)
      CALL PLT1 (RUNAM )
   31 FORMAT (6A4,36X,2I1,I2)
      READ (5,12)                    (FIXINC(I),I=1,3),(OPRINC(I),I=1,3),
     1 NRECEP,METKEY,DELTA,NLCPTS,NPTPTS,NTOTAL
      WRITE(3,852) (FIXINC(I),I=1,3),(OPRINC(I),I=1,3),NRECEP,METKEY,DEL
  852 FORMAT (10X,*INCENTIVE RATES FIX=*,3(2X,F5.1)/
     110X,*INCENTIVE RATES OPR=*,3(2X,F5.1)/10X,*NO. OF RECEPTORS=    *,2
     2X,I4/10X,*METKEY    =                *,2X,I1/10X,*DELTA    =          *,2
     3X,F5.1/10X,*NLCPTS    =                *,2X,I2/10X,*NPTPTS    =
     4*,2X,I1,2X,*NTOTAL = *,I4/)
      READ ( 5,13) (REPLC(I),I=1,NLCPTS)
      WRITE(3,853) (REPLC(I),I=1,NLCPTS)
  853 FORMAT (10X,*REPLC VALUES    =   *,10(2X,F5.1)/)
      READ ( 5,14) (REPPT(I),I=1,NPTPTS)
      WRITE (3,854) (REPPT(I),I=1,NPTPTS)
  854 FORMAT (10X,*REPPT VALUES    =     *,9(2X,F5.1)/)
      DO 40 M=1,NRECEP
      READ (5,15) XRECEP(M), YRECEP(M), POP(M)
      WRITE(3,855) XRECEP(M),YRECEP(M),POP(M)
  855 FORMAT (10X,*RECEPTOR X CO-ORD = *,2X,F5.1,10X,*RECEPTOR Y CO-ORD
     1  = *,2X,F5.1,10X,*  POP VALUE  = *,2X,F5.0/)
   40 CONTINUE
      DO 41 I=1,NTOTAL
      READ ( 5,21) XSRC(I),YSRC(I),HEIGHT(I),SO2(I),(ENAME(I,L),L=1,6),
     1 GEACT(I),WIDTH(I),PART(I),NTECH(I)
      WRITE(3,856) XSRC(I),YSRC(I),HEIGHT(I),SO2(I),(ENAME(I,L),L=1,6),
     1GEACT(I),WIDTH(I),PART(I),NTECH(I)
  856 FORMAT (2X,*XSRC*,1X,F5.1,2X,*YSRC*,1X,F5.1,2X,*HEIGHT*,1X,F6.2,2X
     1,*SO2*,1X,F7.2/2X,*ENAME*,1X,6A4,2X,*GEACT*,1X,F11.5,2X,*WIDTH*,1X
     2,F11.5,*PART*,1X,F7.2,2X,*NTECH*,1X,I1/)
      DO 17 L=1,5
      DO 17 LL=1,5
   17 NOGO(I,L,LL) = 0
      READ ( 5,22) (MOM(K), K=1,20)
   22 FORMAT (20I1)
      WRITE(3,857) (MOM(K),K=1,20)
  857 FORMAT (10X,*MOM VALUES  =    *,20(2X,I1)/)
      DO 18 L=1,19,2
      IF (MOM(L).LE.0) GO TO 16
      N = MOM(L)
      NN=MOM(L+1)
      NOGO(I,N   ,NN ) = 1
   18 NOGO(I,NN  ,N  ) = 1
   16 CONTINUE
      JJ = NTECH(I)
      DO 41 J=1,JJ
      READ( 5,31)(TNAME(I,J,L),L=1,6 ),NOPLEV(I,J),NTYPE(I,J),NCODE(I,J)
      WRITE(3,858) (TNAME(I,J,L),L=1,6),NOPLEV(I,J),NTYPE(I,J),NCODE(I,J
     1)
  858 FORMAT (2X,*TNAME=*,6A4,2X,*NOPLEV=*,I1,2X,*NTYPE=*,I1,2X,*NCODE=*
     1,I2/)
      KK = NOPLEV(I,J)
      DO 41 K=1,KK
      READ( 5,32)SREDUC(I,J,K),PREDUC(I,J,K),FIXCST(I,J,K),OPRCST(I,J,K)
      WRITE(3,859) SREDUC(I,J,K),PREDUC(I,J,K),FIXCST(I,J,K),OPRCST(I,J,
     1K)
  859 FORMAT (2X,*SREDUC=*,F5.1,2X,*PREDUC=*,F5.1,2X,*FIXCST=*,F7.1,2X,*
     1OPRCST=*,F7.1/)
   41 CONTINUE
      CALL PHASE3(NTOTAL,METKEY,NRECEP,EXTOT,PARTOT,SO2TOT)
      DO 1000 I=1,NTOTAL
      CALL PHASE3(I)
      CALL PHASE4(I        ,METKEY,NRECEP,FIRST,DELTA,NLCPTS,NPTPTS,
     1EXTOT,PARTOT,SO2TOT)
 1000 CONTINUE
      CALL PHASE5(NTOTAL,METKEY,NRECEP,FIRST,DELTA,NLCPTS,NPTPTS,
     1EXTOT,PARTOT,SO2TOT,NLCEMS)
      DO 999 I=1,NTOTAL
      DO 999 J=1,10
      CONCST(I,J)=CLOWER(I,J)
  999 CONTINUE
      CALL PCC(NPTPTS,NLCEMS,NTOTAL,SO2TOT,EXTOT,PARTOT)
      CALL PHASE6(NTOTAL,METKEY,NRECEP,FIRST,DELTA,NLCPTS,NPTPTS,
     1EXTOT,PARTOT,SO2TOT)
      CALL PHASE7(NTOTAL,METKEY,NRECEP,FIRST,DELTA,NLCPTS,NPTPTS,
     1EXTOT,PARTOT,SO2TOT,NEPPTS)
      CALL PCC(NPTPTS,NEPPTS,NTOTAL,SO2TOT,EXTOT,PARTOT)
      CALL LPUNCH (NTOTAL,NRECEP,CONCST)
      WRITE(41) NTOTAL, NRECEP
      WRITE(41)                       SO2TOT, EXTOT, (RUNAME(J), J=1,19),
     1 (XRECEP(M), YRECEP(M), M=1,NRECEP), ((ENAME(I,J), J=1,6),
     2 (SCOFF(I,M), M=1,NRECEP), NCURVE(I), EXPOSE(I), SO2(I),
     3 (CONCST(I,L), ECCASR(I,L), L=1,10), I=1,NTOTAL)
      CALL ENDPLT
  900 STOP 555
      END
      SUBROUTINE PHASE2(I)
C     PHASE II
      COMMON/5/ RUNAME(19),FIXINC(3),OPRINC(3),                NTECH(48),
     1              POP(48),REDLC(10),REDPT(5) ,ENAME(48,6),
     2 PART(48),
     3    TNAME(48,5,6),NOPLEV(48,5),SREDUC(48,5,8),PREDUC(48,5,8),
     4 FIXCST(48,5,8),OPRCST(48,5,8),NTYPE(48,5),NCODE(48,5),
     5                FOX(3),OPR(3),PFCOST(    5,8),PVCOST(    5,8),
     6 GFCOST(    5,8),GVCOST(    5,8),PNCOST(    5,8),PSCOST(    5,8),
     7 PPCOST(    5,8),GNCOST(    5,8),GSCOST(    5,8),GPCOST(    5,8),AR(5)
     8,EXPOSE(48),CONCEN(48),NBIG(5),CONBIG(5),XBIG(5),YBIG(5),PER(5)
      DO2 K=1,3
      FOX(K) = FIXINC(K)/100.0
      OPR(K) = OPRINC(K)/100.0
    2 CONTINUE
      L=NTECH(I)
      DO 1 J=1,L
      M=NOPLEV(I,J)
      N = NTYPE(I,J)
      DO 1 K=1,M
      PFCOST(  J,K)= (1.0 - FOX(N))*FIXCST(I,J,K)
      PVCOST(  J,K)= (1.0 - OPR(N))*OPRCST(I,J,K)
      GFCOST(  J,K)= FOX(N)*FIXCST(I,J,K)
      GVCOST(  J,K)= OPR(N)*OPRCST(I,J,K)
      GO TO (3,4,5),N
    3 PNCOST(  J,K) = 0.0
      PSCOST(  J,K) = 0.0
      GNCOST(  J,K) = 0.0
      GSCOST(  J,K) = 0.0
      PPCOST(  J,K) = PVCOST(  J,K) + PFCOST(  J,K)
      GPCOST(  J,K) = GVCOST(  J,K) + GFCOST(  J,K)
      GO TO 1
    4 PPCOST(  J,K) = 0.0
      PSCOST(  J,K) = 0.0
      GPCOST(  J,K) = 0.0
      GSCOST(  J,K) = 0.0
      PNCOST(  J,K) = PVCOST(  J,K) + PFCOST(  J,K)
      GNCOST(  J,K) = GVCOST(  J,K) + GFCOST(  J,K)
      GO TO 1
    5 PPCOST(  J,K) = 0.0
      PNCOST(  J,K) = 0.0
      GPCOST(  J,K) = 0.0
      GNCOST(  J,K) = 0.0
      PSCOST(  J,K) = PVCOST(  J,K) + PFCOST(  J,K)
      GSCOST(  J,K) = GVCOST(  J,K) + GFCOST(  J,K)
    1 CONTINUE
      RETURN
      END
      SUBROUTINE PHASE3(NTOTAL,METKEY,NRECEP,EXTOT,PARTOT,SO2TOT)
C
C     PHASE III
C
      COMMON NOGO(48,5,5),
     1       NCURVE(48), SCOEF(48,30), ECCTPC(48,10), ECCAPR(48,10),
     2       XRECEP(48), YRECEP(48), XSRC(48), YSRC(48), HEIGHT(48),
     3 GFACT(48), WIDTH(48), SO2(48)
      COMMON/5/ RUNAME(19),FIXINC(3),OPRINC(3),          NTECH(48),
     1            POP(48),REDLC(10),REDPT(5) ,ENAME(48,6),
     2 PART(48),
     3    TNAME(48,5,6),NOPLEV(48,5),SREDUC(48,5,8),PREDUC(48,5,8),
     4 FIXCST(48,5,8),OPRCST(48,5,8),NTYPE(48,5),NCODE(48,5),
     5               FOX(3),OPR(3),PFCOST(    5,8),PVCOST(    5,8),
     6 GFCOST(    5,8),GVCOST(    5,8),PWCOST(    5,8),PSCOST(    5,8),
     7 PPCOST(    5,8),GWCOST(    5,8),GSCOST(    5,8),GPCOST(    5,8),AB(5)
     8,EXPOSE(48),CONCEN(48),MBIG(5),CONBIG(5),XBIG(5),YBIG(5),PER(5)
      DIMENSION PERTOT(5)
   45 READ ( 5,60) ((SCOEF(I,M),I=1,NTOTAL),M=1,NRECEP)
   60 FORMAT (8E10.3)
   71 SO2TOT = 0.0
      PARTOT = 0.0
      DO 7 I=1,NTOTAL
      SO2TOT = SO2TOT + SO2(I)
      PARTOT = PARTOT + PART(I)
      EXPOSE(I) = 0.0
      DO 6 M=1,NRECEP
      EXPOSE(I) = EXPOSE(I) +  SCOEF(I,M) * POP(M) * SO2(I)
    6 CONTINUE
      EXPOSE(I) = EXPOSE(I) * 1000.0
    7 CONTINUE
      EXTOT=0.0
      DO 61 I=1,NTOTAL
   61 EXTOT=EXTOT+EXPOSE(I)
      DO 63 M=1,NRECEP
   62 CONCEN(M) = 0.0
      DO 63 I=1,NTOTAL
   63 CONCEN(M) = CONCEN(M) + SCOEF(I,M)*SO2(I)
      DO 65 L=1,5
      MBIG(L)=1
   65 CONBIG(L) = 0.0
      DO 72 M=1,NRECEP
      DO 66 I=1,5
      IF (CONCEN(M).LT.CONBIG(I)) GO TO 66
      IF (5-I) 69,69,67
   67 LIM=5-I
      DO 68 K=1,LIM
      CONBIG(6-K) = CONBIG(5-K)
   68 MBIG(6-K)=MBIG(5-K)
   69 MBIG(I) = M
      CONBIG(I) = CONCEN(M)
      GO TO 72
   66 CONTINUE
   72 CONTINUE
  200 WRITE (3,250)
      DO 201 I=1,NTOTAL
      A=SO2(I)/SO2TOT*100.0
      ATOTAL=ATOTAL+A
      B=PART(I)/PARTOT*100.0
      BTOTAL=BTOTAL+B
  201 WRITE ( 3,251) I, (ENAME(I,J), J=1,6), SO2(I), A, PART(I), B
      WRITE(3,252) SO2TOT,ATOTAL,PARTOT,BTOTAL
      WRITE (3,253)
  204 WRITE (3,254) (MBIG(I),I=1,5)
      DO 211 I=1,5
      K=MBIG(I)
      XBIG(I)=XRECEP(K)
  211 YBIG(I)=YRECEP(K)
      WRITE (3,260) (XBIG(I),YBIG(I),I=1,5)
      WRITE (3,261)
      DO 215 I=1,NTOTAL
      DO 214 J=1,5
      K=MBIG(J)
      AB(J)=SO2(I)*SCOEF(I,K)
      PER(J)=AB(J)/CONCEN(K)*100.0
  214 PERTOT(J)=PERTOT(J)+PER(J)
  215 WRITE (3,262) I,(ENAME(I,J),J=1,6),(AB(J),PER(J),J=1,5)
      WRITE(3,263) (CONBIG(J),PERTOT(J),J=1,5)
      WRITE (3,264)
      DO 220 I=1,NTOTAL
      A=EXPOSE(I)/EXTOT*100.0
      ATOT=ATOT+A
  220 WRITE (3,265) I,(ENAME(I,J),J=1,6),EXPOSE(I),A
      WRITE(3,266) EXTOT,ATOT
      WRITE (3,267)
      DO 225 I=1,NRECEP
  225 WRITE (3,268) I,XRECEP(I),YRECEP(I),CONCEN(I)
  250 FORMAT (*1*/// 53X,*PRE-ABATEMENT EMISSION INVENTORY*///10X,60X,*
     1SO2 EMISSIONS      PARTICULATE          PARTICULATE*/10X,*SOURCE
     2            SOURCE                    SO2 EMISSIONS        AS PERCENT
     3   EMISSIONS           EMISSIONS AS    */10X,*NUMBER*,14X,*NAME*,21X,
     4*(GMS/SEC)          OF TOTAL            (GMS/SEC)         PERCENT OF TOT
     5AL*/)
  251 FORMAT (12X,I2,5X,6A4,11X,F10.1,11X,F4.1,10X,F10.1,13X,F4.1)
  252 FORMAT (/10X,*TOTAL*,39X,F10.1,10X,F5.1,10X,F10.1,12X,F5.1)
  253 FORMAT (1H1///  45X,44HINDIVIDUAL CONTRIBUTIONS TO THE FIVE HIGHES
     1T/54X,32HPRE-ABATEMENT SO2 CONCENTRATIONS/43X,53H(INDIVIDUAL CONTR
     2IBUTION EXPRESSED BOTH IN PPM AND AS/45X,49HPERCENT OF TOTAL CONCE
     3NTRATION AT RECEPTOR POINT))
  254 FORMAT(///40X,5(4X,14HRECEPTOR POINT)/41X,5(4X,1X,7HNUMBER ,I3,3X
     1))
  260 FORMAT (41X,5(4X,13HCO-ORDINATES ,1X)/40X,5(4X,1X,1H(,F5.1,1H,,F5.
     11,1H)))
  261 FORMAT (8X,6HSOURCE,11X,6HSOURCE/8X,6HNUMBER,12X,4HNAME,11X,5(5X
     1,3HPPM, 4X, 4HPER,, 2X)/)
  262 FORMAT (10X   ,I2,4X,6A4,5X,4(F5.3,3X,F4.1,6X),F5.3,3X,F4.1)
  263 FORMAT  (/ 8X,29HTOTAL SO2 CONCENTRATION (PPM),8X,4(F5.3,2X,F5.1,6
     1X),F5.3,2X,F5.1)
  264 FORMAT (1H1//49X,41HINDIVIDUAL CONTRIBUTIONS TO PRE-ABATEMENT/57X,
     1*SO2 EXPOSURE (PEOPLE-PPM)*
     2   //77X,12HSO2 EXPOSURE/36X,           13X,6HSOURCE,13X,12HCONTRIBU
     3TION,9X,7HPERCENT/30X,6HSOURCE,14X,4HNAME,14X,12H(PEOPLE-PPM),9X,8
     4HOF TOTAL/)
  265 FORMAT (32X,I2,6X,6A4,4X,F12.1,11X,F4.1)
  266 FORMAT(/30X,31HTOTAL SO2 EXPOSURE (PEOPLE-PPM),7X,F12.1,10X,F5.1)
  267 FORMAT (1H1///54X,32HPRE-ABATEMENT SO2 CONCENTRATIONS/60X,22HAT EA
     1CH RECEPTOR POINT/31X,*RECEPTOR*/31X,* POINT*,6X,13HX CO-ORDINATE,
     25X,13HY CO-ORDINATE,5X,23HSO2 CONCENTRATION (PPM)/)
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      SUBROUTINE PHASE4(I     ,MEIKEY,NRECEP,FIRST,DELTA,NLCPTS,NPTPTS,
     1EXTOT,PARTOT,SO2TOT)
C
C PHASE IV
C
      COMMON/1/ ECCPFC(48,10),ECCPVC(48,10),ECCPWC(48,10),ECCPPC(48,10),
     1ECCPSC(48,10),ECCGFC(48,10),ECCGVC(48,10),ECCGWC(48,10),ECCGPC(48,
     210),ECCGSC(48,10),LEVECC(48,10,8),                 ECCTGC(48,10),ECCG
     3TC(48,10),ECCPSR(48,10),ECCASR(48,10),ECCUSC(48,10),ECCMSC(48,10),
     4ECCPER(48,10),ECCAER(48,10),ECCUEC(48,10),ECCMEC(48,10),ECCPPR(48,
     510),ECCPST(48,10),ECCPET(48,10),ECCPPT(48,10)
      COMMON/5/ RUNAME(19),FIXINC(3),OPRINC(3),                NTECH(48),
     1           POP(48),REDLC(10),REUPT(5) ,ENAME(48,6),
     2 PART(48),
     3     TNAME(48,5,6),NOPLEV(48,5),SREDUC(48,5,8),PREDUC(48,5,8),
     4 FIXCST(48,5,8),OPRCST(48,5,8),NTYPE(48,5),NCODE(48,5),
     5               FOX(3),OPR(3),PFCOST(   5,8),PVCOST(   5,8),
     6 GFCOST(   5,8),GVCOST(   5,8),PWCOST(   5,8),PSCOST(   5,8),
     7 PPCOST(   5,8),GWCOST(   5,8),GSCOST(   5,8),GPCOST(   5,8),AB(5)
     8,EXPOSE(48),CONCEN(48),NBIG(5),CONBIG(5),XBIG(5),YBIG(5),PER(5)
      COMMON/9/ CLOWER(48,10),LEVE(48),                   NCUR(48),
     1           LOP(48,10,8),RCURVE(48,10),CCURVE(48,10),CLOW(48,10),
     2           LEVELP(48)
      COMMON NOGO(48,5,5),
     1        NCURVE(48), SCOEF(48,30), ECCTPC(48,10), ECCAPR(48,10),
     2        XRECEP(48), YRECEP(48), XSRC(48), YSRC(48), HEIGHT(48),
     3 GFACT(48), WIDTH(48), SO2(48)
      COMMON/4/ SAC(5,10),INDCTR(48,5,10),RED(48,10)
      COMMON/2/ INILEV(48,5)
      COMMON/3/ ACCPFC(10),ACCPVC(10),ACCPPC(10),ACCPWC(10),ACCPSC(10),
     1           ACCTPC(10),ACCGFC(10),ACCGVC(10),ACCGPC(10),ACCGWC(10),
     2           ACCGSC(10),ACCTGC(10),ACCGTC(10),ACCPSR(10),ACCASR(10),
     3           ACCAER(10),ACCUSC(10),ACCMSC(10),ACCUEC(10),ACCMEC(10),
    4          ACCPPR(10),ACCAPR(10),ACCPER(10)
      COMMON/7/ DATA(12,2,7)
      COMMON/23/  ENAM(3),RUNAM(10),PERCENTS(7)
      FIRST=0.0
      LIM=NTECH(I)
      DO 300 J=1,LIM
  300 INILEV(I,J)=1
      CALL COST (I,FIRST,DELTA,NTECH,NOPLEV,PFCOST,NCODE,PVCOST,SREDUC,N
     1CURVE,LEVECC,ECCPSR,ECCTPC,INILEV)
      NC=NCURVE(I)
      NT=NTECH(I)
      DO 320 L=1,NC
      ECCPFC(I,L)=0.0
      ECCPVC(I,L)=0.0
      ECCPWC(I,L)=0.0
      ECCPPC(I,L)=0.0
      ECCPSC(I,L)=0.0
      ECCGFC(I,L)=0.0
      ECCGVC(I,L)=0.0
      ECCGWC(I,L)=0.0
      ECCGPC(I,L)=0.0
      ECCGSC(I,L)=0.0
      ECCPSR(I,L)=0.0
      ECCPPR(I,L)=0.0
      ECCPER(I,L)=0.0
      ECCPET(I,L)=0.0
      ECCPPT(I,L)=0.0
      ECCPST(I,L)=0.0
      DO 310 J=1,NT
       K=LEVECC(I,L,J)
       ECCPFC(I,L)=ECCPFC(I,L)+PFCOST(   J,K)
       ECCPVC(I,L)=ECCPVC(I,L)+PVCOST(   J,K)
       ECCPWC(I,L)=ECCPWC(I,L)+PWCOST(   J,K)
       ECCPPC(I,L)=ECCPPC(I,L)+PPCOST(   J,K)
       ECCPSC(I,L)=ECCPSC(I,L)+PSCOST(   J,K)
       ECCGFC(I,L)=ECCGFC(I,L)+GFCOST(   J,K)
       ECCGVC(I,L)=ECCGVC(I,L)+GVCOST(   J,K)
       ECCGWC(I,L)=ECCGWC(I,L)+GWCOST(   J,K)
       ECCGPC(I,L)=ECCGPC(I,L)+GPCOST(   J,K)
       ECCGSC(I,L)=ECCGSC(I,L)+GSCOST(   J,K)
      IF(K-1)301,310,301
  301 IF(NCODE(I,J)-10)302,304,304
  302 ECCPSR(I,L)=ECCPSR(I,L)+SREDUC(I,J,K)
      ECCPPR(I,L)=ECCPPR(I,L)+PREDUC(I,J,K)
      GO TO 310
  304 ECCPSR(I,L)= ECCPSR(I,L)+(100.0-ECCPSR(I,L))+SREDUC(I,J,K)/100.0
      ECCPPR(I,L)= ECCPPR(I,L)+(100.0-ECCPPR(I,L))*PREDUC(I,J,K)/100.0
  310 CONTINUE
      ECCTPC(I,L)=ECCPVC(I,L)+ECCPFC(I,L)
      ECCTGC(I,L)=ECCGVC(I,L)+ECCGFC(I,L)
      ECCGTC(I,L)=ECCTPC(I,L)+ECCTGC(I,L)
      ECCAPR(I,L)=ECCPPR(I,L)*PART(I)/100.0
      ECCASR(I,L)=ECCPSR(I,L)*SO2(I)/100.0
      ECCAER(I,L)=ECCPSR(I,L)*EXPOSE(I)/100.0
      ECCPST(I,L)=(ECCASR(I,L)/SO2TOT)*100.0
      ECCPER(I,L)=(ECCAER(I,L)/EXPOSE(I))*100.0
      ECCPET(I,L)=(ECCAER(I,L)/EXTOT)*100.0
      ECCPPT(I,L)=(ECCAPR(I,L)/PARTOT)*100.0
      IF (ECCASR(I,L)) 305,305,306
  305 ECCUSC(I,L)=0.0
      ECCUEC(I,L)=0.0
      GO TO 307
  306 ECCUSC(I,L)=ECCTPC(I,L)/ECCASR(I,L)
      ECCUEC(I,L)=ECCTPC(I,L)/ECCAER(I,L)
  307 IF (L-1)  320,320,311
  311 ECCMSC(I,L)=(ECCTPC(I,L)-ECCTPC(I,L-1))/(ECCASR(I,L)-ECCASR(I,L-1)
     1)
       ECCMEC(I,L)=(ECCTPC(I,L)-ECCTPC(I,L-1))/(ECCAER(I,L)-ECCAER(I,L-1)
     1)
   320 CONTINUE
      ENCODE(24,994,ENAM(1)) (ENAME(I,II),II=1,6)
  994 FORMAT (6A4)
      NPOINTS=NCURVE(I)
      DO 445 L=1,NPOINTS
      DATA(L,1,1)=DATA(L,1,2)=ECCPSR(I,L)
      DATA(L,2,1)=ECCTPC(I,L)  $  DATA(L,2,2)=ECCGTC(I,L)
  445 CONTINUE
      CALL PLT2 (ENAM ,RUNAM ,DATA,NPOINTS)
      WRITE (3,450)
      WRITE (3,551) (RUNAME(J),J=1,19)
      WRITE (3,451) I,(ENAME(I,J),J=1,6)
      LIM=NCURVE(I)
      WRITE (3,552)(L,L=1,LIM)
      WRITE(3,553) (ECCPSR(I,L),L=1,LIM)
      WRITE(3,5531) (ECCPST(I,L),L=1,LIM)
      WRITE(3,5532)          (ECCASR(I,L),L=1,LIM)
      WRITE(3,554) (ECCPER(I,L),L=1,LIM)
      WRITE(3,5531) (ECCPET(I,L),L=1,LIM)
      WRITE(3,5541) (ECCAER(I,L),L=1,LIM)
      WRITE (3,555)(ECCPFC(I,L),L=1,LIM)
      WRITE (3,556)(ECCPVC(I,L),L=1,LIM)
      WRITE (3,557)(ECCPPC(I,L),L=1,LIM)
      WRITE (3,558)(ECCPRC(I,L),L=1,LIM)
      WRITE (3,559)(ECCPSC(I,L),L=1,LIM)
      WRITE (3,560)(ECCTPC(I,L),L=1,LIM)
      WRITE (3,561)(ECCGFC(I,L),L=1,LIM)
      WRITE (3,556)(ECCGVC(I,L),L=1,LIM)
      WRITE (3,557)(ECCGPC(I,L),L=1,LIM)
      WRITE (3,558)(ECCGRC(I,L),L=1,LIM)
      WRITE (3,559)(ECCGSC(I,L),L=1,LIM)
      WRITE(3,595) (ECCTSC(I,L),L=1,LIM)
      WRITE (3,567)(ECCGIC(I,L),L=1,LIM)
      WRITE(3,568) (ECCJSC(I,L),L=1,LIM)
      WRITE(3,5581) (ECCUEC(I,L),L=1,LIM)
      IF (NCURVE(I)-1) 443,443, 442
  442 WRITE(3,569) (ECCMSC(I,L),L=2,LIM)
      WRITE(3,5691) (ECCMEC(I,L),L=2,LIM)
  443 WRITE(3,570) (ECCPPR(I,L),L=1,LIM)
      WRITE(3,5701) (ECCPPT(I,L),L=1,LIM)
      WRITE(3,571) (ECCAPR(I,L),L=1,LIM)
      WRITE (3,460)
      MAX=NTECH(I)
      DO 445 J=1,MAX
  445 WRITE (3,461) J,(TNAME(I,J,K),K=1,6),(LEVECC(I,L,J),L=1,LIM)
  460 FORMAT (1H1                         ///10X,21HLEVEL OF OPERATION
     10F/10X,5HTECH,,10X,5HTECH,/11X,3HNO.,11X,4HNAME/)
  461 FORMAT (11X,I2,3X,6A4,1X,10(2X,I5,2X)/)
  450 FORMAT  (1H1,25X,93HELEMENTAL COST CURVE FOR REDUCTION OF SO2 EMIS
     1SIONS AND REDUCTION OF HUMAN EXPOSURE TO SO2)
  551 FORMAT (32X,19A4)
  451 FORMAT( //10X,14HSOURCE NUMBER ,1X,I2,10X,12HSOURCE NAME=,6A4)
  552 FORMAT (  /10X,17HCALCULATION POINT,16X,10(3X,I2,4X))
  553 FORMAT(/10X,13HSO2 EMISSIONS/12X,17HPERCENT REDUCTION/14X,6HSOURCE
     1,23X,10(2X,F4,1,3X))
  531 FORMAT (14X,5HTOTAL,24X,10(2X,F4,1,3X))
  532 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9,1)
  554 FORMAT (/10X,12HSO2 EXPOSURE/12X,17HPERCENT REDUCTION/14X,6HSOURCE
     1,23X,10(2X,F4,1,3X))
  541 FORMAT (12X,18HABSOLUTE REDUCTION,3X,7H(P-PPM),10F9,1)
  555 FORMAT( /10X,13HPRIVATE COSTS /12X,5HFIXED,15X,8H($X1000),10F9.1)
  556 FORMAT(12X,8HVARIABLE,12X,8H($X1000),10F9.1)
  557 FORMAT( 12X,14HPROCESS CHANGE,5X,8H($X1000),10F9.1)
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149

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558 FORMAT(12X,15HWASTE TREATMENT,5X,8H($X1000),10F9.1)
559 FORMAT(12X,17HFUEL SUBSTITUTION,3X,8H($X1000),10F9,1)
560 FORMAT (12X,16HTOTAL PRIVATE COST,2X,8H($X1000),10F9,1)
595 FORMAT (12X,15HTOTAL GOVT COST,5X,8H($X1000),10F9,1)
561 FORMAT( /10X,16HGOVERNMENT COSTS /12X,5HFIXED,15X,8H($X1000),10F9.
   11)
567 FORMAT( /10X,16HGRAND TOTAL COST,6X,8H($X1000),10F9,1)
568 FORMAT (/10X,29HUNIT PRIVATE COST OF REDUCING/12X,10HSO2 EMISNS,3X
   1,15H($X1000/GM/SEC),2X,9F9.3/)
681 FORMAT (12X,12HSO2 EXPOSURE,2X,14H($X1000/P-PPM),2X,9F9.3/)
569 FORMAT(/10X,30HMARGINAL PRVT COST OF REDUCING/12X,10HSO2 EMISNS,3X
   1,15H($X1000/GM/SEC),5X,9F9.3)
691 FORMAT  (12X,12HSO2 EXPOSURE,2X,14H($X1000/P-PPM),5X,9F9.3/)
570 FORMAT (/10X,18HBONUS REDUCTION IN/10X,21HPARTICULATE EMISSIONS/12
   1X,17HPERCENT REDUCTION/14X,6HSOURCE,23X,10(2X,F4.1,3X))
701 FORMAT (14X,5HTOTAL,24X,10(2X,F4.1,3X))
571 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9,1)
    RETURN
    END
```

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      SUBROUTINE PHASEV(NTOTAL [illegible]S) [illegible],FIRST,DELTA,NLCPTS,NPTPTS,
     1EXTOT,PARTOT,SO2TOT,[illegible]LCB
C
C PHASE V
C
      COMMON/1/ ECCPFC(48,10),ECCPVC(48,10),ECCPPC(48,10),ECCPPC(48,10),
     1ECCPSC(48,10),ECCGFC(48,10),ECCGVC(48,10),ECCGWC(48,10),ECCGPC(48,
     210),ECCGSC(48,10),LEVECC(48,10,8),                ECCTGC(48,10),ECCG
     3TC(48,10),ECCPSR(48,10),ECCASR(48,10),ECCUSC(48,10),ECCMSC(48,10),
     4ECCPER(48,10),ECCAER(48,10),ECCUEC(48,10),ECCMEC(48,10),ECCPPR(48,
     510),ECCPST(48,10),ECCPET(48,10),ECCPPT(48,10)
      COMMON/5/ RUNAME(19),FIXINC(3),OPRINC(3),               NTECH(48),
     1           POP(48),REDLC(10),REDPT(5) ,ENAME(48,6),
     2 PART(48),
     3    TNAME(48,5,6),NOPLEV(48,2),SREDUC(48,5,8),PREDUC(48,5,8),
     4 FIXCST(48,5,8),OPRCST(48,5,8),NTYPE(48,5),NCODE(48,5),
     5           FOX(3),OPR(3),PFCOST(   5,8),PVCOST(   5,8),
     6 GFCOST(   5,8),GVCOST(   5,8),PWCOST(   5,8),PSCOST(   5,8),
     7 PPCOST(   5,8),GWCOST(   5,8),GSCOST(   5,8),GPCOST(   5,8),AB(5)
     8,EXPOSE(48),CONCRN(48),NBIG(5),CONBIG(5),XBIG(5),YBIG(5),PER(5)
      COMMON/9/ CLOWER(48,10),LEVE(48),                  NCUR(48),
     1          LOP(48,10,8),RCURVE(48,10),CCURVE(48,10),CLOW(48,10),
     2          LEVELP(48)
      COMMON NOGO(48,2,5),
     1        NCURVE(48), SCOFF(48,30), ECCTPC(48,10), ECCAPR(48,10),
     2        XRECEP(48), YRECEP(48), XSRC(48), YSRC(48), HEIGHT(48),
     3 GFACT(48), WIDTH(48), SO2(48)
      COMMON/4/ SAC(5,10),IMPCTR(48,5,10),RED(48,10)
      COMMON/2/ INILEV(48,5)
      COMMON/3/ ACCPFC(10),ACCPVC(10),ACCPPC(10),ACCPWC(10),ACCPSC(10),
     1          ACCTPC(10),ACCGFC(10),ACCGVC(10),ACCGPC(10),ACCGWC(10),
     2          ACCGSC(10),ACCTGC(10),ACCGTC(10),ACCPSR(10),ACCASR(10),
     3          ACCAER(10),ACCUSC(10),ACCMSC(10),ACCUEC(10),ACCMEC(10),
     4          ACCPPR(10),ACCAPR(10),ACCPER(10)
      COMMON/7/ DATA(12,2,7)
      COMMON/20/  ENAM(3),RUNAM(10),PERCENTS(7)
      WRITE ( 3,3106)
 3106 FORMAT (1H1///)
  500 DO 501 I=1,NTOTAL
  501 CALL ENVLPE (I,ECCTPC,NCURVE,ECCASR,CLOWER)
      DO 540 N=1,NLCPTS
      ABSOBJ=SO2TOT*REDLC(N)/100.0
      CALL SOLUTN(NTOTAL,ABSOBJ,NCURVE,CLOWER,ECCASR,LEVE,LRTEST)
      ACCPFC(N)=0.0
      ACCPVC(N)=0.0
      ACCPPC(N)=0.0
      ACCPWC(N)=0.0
      ACCPSC(N)=0.0
      ACCTPC(N)=0.0
      ACCPER(N)=ACCAER(N)=0.0
      ACCGFC(N)=0.0
      ACCGVC(N)=0.0
      ACCGPC(N)=0.0
      ACCGWC(N)=0.0
      ACCGSC(N)=0.0
      ACCTGC(N)=0.0
      ACCGTC(N)=0.0
      ACCASR(N)=0.0
      ACCAPR(N)=0.0
      ACCPFC(N)=ACCPFC(N)+ECCPFC(I,L)
      ACCPVC(N)=ACCPVC(N)+ECCPVC(I,L)
      ACCPPC(N)=ACCPPC(N)+ECCPPC(I,L)
      ACCPRC(N)=ACCPRC(N)+ECCPRC(I,L)
      ACCPSC(N)=ACCPSC(N)+ECCPSC(I,L)
      ACCTPC(N)=ACCTPC(N)+ECCTPC(I,L)
      ACCGFC(N)=ACCGFC(N)+ECCGFC(I,L)
      ACCGVC(N)=ACCGVC(N)+ECCGVC(I,L)
      ACCGPC(N)=ACCGPC(N)+ECCGPC(I,L)
      ACCGRC(N)=ACCGRC(N)+ECCGRC(I,L)
      ACCGSC(N)=ACCGSC(N)+ECCGSC(I,L)
      ACCTGC(N)=ACCTGC(N)+ECCTGC(I,L)
      ACCGTC(N)=ACCGTC(N)+ECCGTC(I,L)
      ACCASR(N)=ACCASR(N)+ECCASR(I,L)
      ACCAER(N)=ACCAER(N)+ECCAER(I,L)
  510 ACCAPR(N)=ACCAPR(N)+ECCAPR(I,L)
      ACCPSR(N)=ACCASR(N)/SO2TOT*100.0
      ACCPER(N)=ACCAER(N)/EXTOT*100.0
      IF (ACCASR(N)) 502,502,503
  502 ACCUSC(N)=0.0
      ACCUEC(N)=0.0
      GO TO 504
  503 ACCUSC(N)=ACCTPC(N)/ACCASR(N)
      ACCUEC(N)=ACCTPC(N)/ACCAER(N)
  504 IF(N-1) 511,511,505
  505 IF (ACCASR(N)-ACCASR(N-1)) 511,511,512
  511 ACCMSC(N)=0.0
      ACCMEC(N)=0.0
      GO TO 513
  512 ACCMSC(N)=(ACCTPC(N)-ACCTPC(N-1))/(ACCASR(N)-ACCASR(N-1))
      ACCMEC(N)=(ACCTPC(N)-ACCTPC(N-1))/(ACCAER(N)-ACCAER(N-1))
  513 ACCPPR(N)=ACCAPR(N)/PARTOT*100.0
      DO 517 I=1,NTOTAL
      CALL PHASE2 (I)
      L=LEVE(I)
      LIM=NTECH(I)
      DO 514 J=1,LIM
  514 INILEV(I,J)=LEVECC(I,L,J)
      FIRST=ECCPPR(I,L)
      CALL COST (I,FIRST,DELTA,NTECH,NOPLEV,PFCOST ,NCODE,PVCOST,PREDUC,
     1NCUR,LOP,RCURVE,CCURVE,INILEV)
      LIM=NCUR(I)
      DO 516 J=1,LIM
  516 RCURVE(I,J)=RCURVE(I,J)*PART(I)
  517 CALL ENVLPE (I,CCURVE,NCUR,RCURVE,CLOW)
      LMN=LEVE(6)
      WRITE ( 3,3107) LMN,LEVECC(6,LMN,1),INILEV(6,1), (LOP(6,NN,1),
     1   NN=1,10)
 3107 FORMAT (13I8)
      DO 530 M=1,NPTPTS
      IF (PERPT(M)-ACCPPR(N))  518,518,520
  518 SAC(M,N)=0.0
      DO 519 I=1,NTOTAL
      L=LEVE(I)
      INDCTR(I,M,N)=0
      LIM=NTECH(I)
      DO 519 J=1,LIM
  519 INDCTR(I,M,N)=INDCTR(I,M,N)+LEVECC(I,L,J)*10**(J-1)
      GO TO 530
  520 OBJ=PERPT(M)*PARTOT/100.0
      CALL SOLUTN (NTOTAL, [illegible]
 6108 FORMAT (  13X, I10)
      IF(LTEST) 523,523,521
  521 LIM=NPTPTS-M+1
      DO 522 J=1,LIM
      L=M+J-1
      SAC(M,N)=-5.0
      DO 522 I=1,NTOTAL
  522 INDCTR(I,L,N)=0
      GO TO 531
  523 SAC(M,N)=0.0
      DO 525 I=1,NTOTAL
      INDCTR(I,M,N)=0
      K=LEVELP(I)
      SAC(M,N)=SAC(M,N)+CCURVE(I,K)
      LIM=NTECH(I)
      DO 524 J=1,LIM
  524 INDCTR(I,M,N)=INDCTR(I,M,N)+LUP(I,K,J)*10**(J-1)
  525 CONTINUE
      SAC(M,N)=SAC(M,N)-ACCTPC(N)
  530 CONTINUE
  531 IF (LRTEST) 540,540,532
  532 NLCEMS=N
      GO TO 541
  540 CONTINUE
      NLCEMS=NLCPTS
  541 WRITE (3,550)
      NPOINTS=NLCEMS
      DO 6401 J=1,NPOINTS
      DATA(J,1,1)=DATA(J,1,2)=ACCPSR(J)
      DATA(J,2,1)=ACCTPC(J)  $  DATA(J,2,2)=ACCGTC(J)
 6401 CONTINUE
      CALL PLT6(RUNAM , DATA,NPOINTS)
      WRITE (3,551)(RUNAME(I),I=1,19)
      WRITE (3,552)(I,I=1,NLCEMS)
      WRITE(3,553) (ACCPSR(I),I=1,NLCEMS)
      WRITE(3,5531) (ACCASR(I),I=1,NLCEMS)
      WRITE (3,554)(ACCPER(I),I=1,NLCEMS)
      WRITE(3,5541) (ACCAER(I),I=1,NLCEMS)
      WRITE (3,555)(ACCPFC(I),I=1,NLCEMS)
      WRITE (3,556)(ACCPVC(I),I=1,NLCEMS)
      WRITE (3,557)(ACCPPC(I),I=1,NLCEMS)
      WRITE (3,558)(ACCPMC(I),I=1,NLCEMS)
      WRITE (3,559)(ACCPSC(I),I=1,NLCEMS)
      WRITE (3,560)(ACCTPC(I),I=1,NLCEMS)
      WRITE (3,561)(ACCGFC(I),I=1,NLCEMS)
      WRITE (3,556)(ACCGVC(I),I=1,NLCEMS)
      WRITE (3,557)(ACCGPC(I),I=1,NLCEMS)
      WRITE (3,558)(ACCGMC(I),I=1,NLCEMS)
      WRITE (3,559)(ACCGSC(I),I=1,NLCEMS)
      WRITE(3,595) (ACCTGC(I),I=1,NLCEMS)
      WRITE (3,567)(ACCGTC(I),I=1,NLCEMS)
      WRITE (3,568) (ACCUSC(I),I=1,NLCEMS)
      WRITE(3,5681) (ACCUEC(I),I=1,NLCEMS)
      IF (NLCEMS-1) 543,543,542
  542 WRITE(3,569) (ACCMSC(I),I=2,NLCEMS)
      WRITE(3,5691) (ACCMEC(I),I=2,NLCEMS)
  543 WRITE (3,570)(ACCPPR(I),I=1,NLCEMS)
      WRITE (3,571)(ACCAPR(I),I=1,NLCEMS)
      WRITE (3,574)
      WRITE (3,575) (I,I=1,NLCEMS)
      DO 545 I=1,NTOTAL
      WRITE (3,577)  I,(ENAME(I,J),J=1,6),(RED(I,J),J=1,NLCEMS)
      DO 545 M=1,NPTPTS
      PERCENTS(M)=REDPT(M)
  545 WRITE (3,578)  REDPT(M),(INDCTR(I,M,N),N=1,NLCEMS)
      NOLINES=NPTPTS
      CALL PLT3 (RUNAM ,PERCENTS,NOLINES)
  550 FORMAT (1H1///41X,57HAGGREGATE LEAST-COST CURVE FOR REDUCTION OF S
     102 EMISSIONS)
  551 FORMAT (32X,      1944     )
  552 FORMAT (//10X,17HCALCULATION POINT,16X,10(3X,I2,4X))
  553 FORMAT (/10X,13HSO2 EMISSIONS/12X,17HPERCENT REDUCTION,14X,10(2X,F
     14.1, 3X))
 5531 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9.1)
  554 FORMAT (/10X,13HSO2 EXPOSURES/12X,17HPERCENT REDUCTION,14X,10(2X,F
     14.1,3X))
 5541 FORMAT (12X,18HABSOLUTE REDUCTION,3X,7H(P-PPM),10F9.1)
  555 FORMAT( /10X,13HPRIVATE COSTS /12X,5HFIXED,15X,8H($X1000),10F9.1)
  556 FORMAT(12X,8HVARIABLE,12X,8H($X1000),10F9.1)
  557 FORMAT( 12X,14HPROCESS CHANGE,6X,8H($X1000),10F9.1)
  558 FORMAT(12X,15HWASTE TREATMENT,5X,8H($X1000),10F9.1)
  559 FORMAT(12X,17HFUEL SUBSTITUTION,3X,8H($X1000),10F9.1)
  560 FORMAT (12X,18HTOTAL PRIVATE COST,2X,8H($X1000),10F9.1)
  595 FORMAT (12X,15HTOTAL GOVT COST,5X,8H($X1000),10F9.1)
  561 FORMAT( /10X,16HGOVERNMENT COSTS /12X,5HFIXED,15X,8H($X1000),10F9.
     11)
  567 FORMAT( /10X,16HGRAND TOTAL COST,6X,8H($X1000),10F9.1)
  568 FORMAT (/10X,29HUNIT PRIVATE COST OF REDUCING/12X,10HSO2 EMISNS,3X
     1,15H($X1000/GM/SEC),2X,9F9.3/)
 5681 FORMAT (12X,12HSO2 EXPOSURE,2X,14H($X1000/P-PPM),2X,9F9.3/)
  569 FORMAT(/10X,30HMARGINAL PRVT COST OF REDUCING/12X,10HSO2 EMISNS,3X
     1,15H($X1000/GM/SEC),5X,9F9.3)
 5691 FORMAT  (12X,12HSO2 EXPOSURE,2X,14H($X1000/P-PPM),5X,9F9.3/)
  570 FORMAT (/10X,18HBONUS REDUCTION IN/10X,21HPARTICULATE EMISSIONS/12
     1X,17HPERCENT REDUCTION,14X,10(2X,F4.1,3X))
  571 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9.1)
  574 FORMAT (1H1///36X,62HINDIVIDUAL EMISSION REDUCTION REQUIREMENT AT
     1EACH POINT ON THE/38X,57HAGGREGATE LEAST-COST CURVE FOR REDUCTION
     2OF SO2 EMISSIONS/31X,72H(REQUIREMENT EXPRESSED AS PERCENT OF TOTAL
     3 SO2 EMISSIONS OF EACH SOURCE)///9X,17HCOMPUTATION POINT)
  575 FORMAT (12X,6HSOURCE,15X,6HSOURCE/12X,6HNUMBER,16X,4HNAME,14X,
     110(3X,I2,3X))
  577 FORMAT (/14X,I2,8X,6A4,4X,10(2X,F4.1,2X))
  578 FORMAT (31X,5HKEY  ,F5.1,11X,10(1X,I5,2X))
      RETURN
      END
      SUBROUTINE PHASE6(NTOTAL,METKEY,NRECEP,FIRST,DELTA,NLCPTS,NPTPTS,
     1EXTOT,PARTOT,SO2TOT)
C
C PHASE VI
C
      COMMON/1/ ECCPFC(48,10),ECCPVC(48,10),ECCPWC(48,10),ECCPPC(48,10),
     1ECCPSC(48,10),ECCGFC(48,10),ECCGVC(48,10),ECCGWC(48,10),ECCGPC(48,
     210),ECCGSC(48,10),LEVECC(48,10,8),          ECCTGC(48,10),ECCG
     3TC(48,10),ECCPSR(48,10),ECCASR(48,10),ECCUSC(48,10),ECCMSC(48,10),
     4ECCPER(48,10),ECCAER(48,10),ECCUEC(48,10),ECCMEC(48,10),ECCPPR(48,
     510),ECCPST(48,10),ECCPET(48,10),ECCPPT(48,10)
      COMMON/5/ RUNAME(19),FIXINC(3),OPRINC(3),          NTECH(48),
     1              POP(48),REDLC(10),REDPT(5) ,ENAME(48,6),
     2 PART(48),
     3    TNAME(48,5,6),NOPLEV(48,5),SREDUC(48,5,8),PREDUC(48,5,8),
     4 FIXCST(48,5,8),OPRCST(48,5,8),NTYPE(48,5),NCODE(48,5),
     5                FOX(3),OPR(3),PFCOST(    5,8),PVCOST(    5,8),
     6 GFCOST(    5,8),GVCOST(    5,8),PWCOST(    5,8),PSCOST(    5,8),
     7 PPCOST(    5,8),GWCOST(    5,8),GSCOST(    5,8),GPCOST(    5,8),AB(5)
     8,EXPOSE(48),CONCEN(48),MBIG(5),CONBIG(5),XBIG(5),YBIG(5),PER(5)
      COMMON/9/ CLOWER(48,10),LEVE(48),                NCUR(48),
     1          LOP(48,10,8),RCURVE(48,10),CCURVE(48,10),CLOW(48,10),
     2          LEVELP(48)
      COMMON NOGO(48,2,5),
     1        NCURVE(48), SCOEF(48,30), ECCTPC(48,10), ECCAPR(48,10),
     2        XRECEP(48), YRECEP(48), XSRC(48), YSRC(48), HEIGHT(48),
     3 GFACT(48), WIDTH(48), SO2(48)
      COMMON/4/ SAC(5,10),INDCTR(48,5,10),RED(48,10)
      COMMON/2/ INILEV(48,5)
      COMMON/3/ ACCPFC(10),ACCPVC(10),ACCPPC(10),ACCPWC(10),ACCPSC(10),
     1          ACCTPC(10),ACCGFC(10),ACCGVC(10),ACCGPC(10),ACCGWC(10),
     2          ACCGSC(10),ACCTGC(10),ACCGTC(10),ACCPSR(10),ACCASR(10),
     3          ACCAER(10),ACCUSC(10),ACCMSC(10),ACCUEC(10),ACCMEC(10),
     4          ACCPPR(10),ACCAPR(10),ACCPER(10)
      COMMON/7/ DATA(12,2,7)
      COMMON/20/  ENAM(3),RUNAM(10),PERCENTS(7)
  600 DO 601 I=1,NTOTAL
  601 CALL ENVLPE (I,ECCTPC,NCURVE,ECCAER,CLOWER)
      DO 640 N=1,NLCPTS
      ABSOBJ=EXTOT*REDLC(N)/100.0
      CALL SOLUTN (NTOTAL,ABSOBJ,NCURVE,CLOWER,ECCAER,LEVE,LRTEST)
      ACCPVC(N)=0.0
      ACCPFC(N)=0.0
      ACCPPC(N)=0.0
      ACCPWC(N)=0.0
      ACCPSC(N)=0.0
      ACCTPC(N)=0.0
      ACCGFC(N)=0.0
      ACCGVC(N)=0.0
      ACCGPC(N)=0.0
      ACCGWC(N)=0.0
      ACCGSC(N)=0.0
      ACCTGC(N)=0.0
      ACCGTC(N)=0.0
      ACCAER(N)=0.0
      ACCAPR(N)=0.0
      ACCASR(N)=ACCPSR(N)=0.0
      DO 610 I=1,NTOTAL
      L=LEVE(I)
      RED(I,N)=ECCPSR(I,L)
      ACCPFC(N)=ACCPFC(N)+ECCPFC(I,L)
      ACCPVC(N)=ACCPVC(N)+ECCPVC(I,L)
      ACCPPC(N)=ACCPPC(N)+ECCPPC(I,L)
      ACCPWC(N)=ACCPWC(N)+ECCPWC(I,L)
      ACCPSC(N)=ACCPSC(N)+ECCPSC(I,L)
      ACCTPC(N)=ACCTPC(N)+ECCTPC(I,L)
      ACCGFC(N)=ACCGFC(N)+ECCGFC(I,L)
      ACCGVC(N)=ACCGVC(N)+ECCGVC(I,L)
      ACCGPC(N)=ACCGPC(N)+ECCGPC(I,L)
      ACCGWC(N)=ACCGWC(N)+ECCGWC(I,L)
      ACCGSC(N)=ACCGSC(N)+ECCGSC(I,L)
      ACCTGC(N)=ACCTGC(N)+ECCTGC(I,L)
      ACCGTC(N)=ACCGTC(N)+ECCGTC(I,L)
      ACCASR(N)=ACCASR(N)+ECCASR(I,L)
      ACCAER(N)=ACCAER(N)+ECCAER(I,L)
  610 ACCAPR(N)=ACCAPR(N)+ECCAPR(I,L)
      ACCPSR(N)=ACCASR(N)/SO2TOT*100.0
      ACCPER(N)=ACCAER(N)/EXTOT*100.0
      IF (ACCAER(N)) 602,602,603
  602 ACCUEC(N)=0.0
      ACCUSC(N)=0.0
      GO TO 604
  603 ACCUEC(N)=ACCTPC(N)/ACCAER(N)
      ACCUSC(N)=ACCTPC(N)/ACCASR(N)
  604 IF (N-1) 611,611,605
  605 IF (ACCAER(N)-ACCAER(N-1)) 611,611,612
  611 ACCMEC(N)=0.0
      ACCMSC(N)=0.0
      GO TO 613
  612 ACCMEC(N)=(ACCTPC(N)-ACCTPC(N-1))/(ACCAER(N)-ACCAER(N-1))
      ACCMSC(N)=(ACCTPC(N)-ACCTPC(N-1))/(ACCASR(N)-ACCASR(N-1))
  613 ACCPPR(N)=ACCAPR(N)/PARTOT*100.0
      DO 617 I=1,NTOTAL
      CALL PHASE2 (I)
      L=LEVE(I)
      LIM=NTECH(I)
      DO 614 J=1,LIM
  614 INILEV(I,J)=LEVECC(I,L,J)
      FIRST=ECCPPR(I,L)
      CALL COST (I,FIRST,DELTA,NTECH,NOPLEV,PFCOST,NCODE,PVCOST,PREDUC,
     1NCUR,LOP,RCURVE,CCURVE,INILEV)
      LIM=NCUR(I)
      DO 615 J=1,LIM
  615 RCURVE(I,J)=RCURVE(I,J)*PART(I)
  617 CALL ENVLPE (I,CCURVE,NCUR,RCURVE,CLOW)
      DO 650 M=1,NPTPTS
      IF (REDPT(M)-ACCPPR(N))618,618,620
  618 SAC(M,N)=0.0
      DO 619 I=1,NTOTAL
      L=LEVE(I)
      INDCTR(I,M,N)=0
      LIM=NTECH(I)
      DO 619 J=1,LIM
  619 INDCTR(I,M,N)=INDCTR(I,M,N)+LEVECC(I,L,J)*10**(J-1)
      GO TO 630
  620 OBJ=REDPT(M)*PARTOT/100.0
      CALL SOLUTN (NTOTAL,OBJ,YCUR,CLOW,RCURVE,LEVELP,LTEST)
      IF(LTEST)623,623,621
  621 LIM=NPTPTS-M+1
      DO 622 J=1,LIM
      L=M+J-1
      SAC(M,N)=-5.0
      DO 622 I=1,NTOTAL
  622 INDCTR(I,L,N)=0
      GO TO 631
  623 SAC(M,N)=0.0
      DO 625 I=1,NTOTAL
      INDCTR(I,M,N)=0
      K=LEVELP(I)
      SAC(M,N)=SAC(M,N)+CCURVE(I,K)
      LIM=NTECH(I)
      DO 624 J=1,LIM
  624 INDCTR(I,M,N)=INDCTR(I,M,N)+LOP(I,K,J)*10**(J-1)
  625 CONTINUE
      SAC(M,N)=SAC(M,N)-ACCTPC(N)
  630 CONTINUE
  631 IF (LRTEST) 640,640,632
  632 NLCEXP=N
      GO TO 641
  640 CONTINUE
      NLCEXP=NLCPTS
  641 WRITE (3,650)
      NPOINTS=NLCEXP
      DO 6401 J=1,NPOINTS
      DATA(J,1,1)=DATA(J,1,2)=ACCPSR(J)
      DATA(J,2,1)=ACCIPC(J)  $  DATA(J,2,2)=ACCGIC(J)
 6401 CONTINUE
      CALL PLT4(RUNAM , DATA,NPOINTS)
      WRITE (3,551)(RUNAME(I),I=1,19)
      WRITE (3,552)(I,I=1,NLCEXP)
      WRITE (3,553)(ACCPSR(I),I=1,NLCEXP)
      WRITE(3,5531) (ACCASR(I),I=1,NLCEXP)
      WRITE (3,554)(ACCPER(I),I=1,NLCEXP)
      WRITE(3,5541) (ACCAER(I),I=1,NLCEXP)
      WRITE (3,555)(ACCPFC(I),I=1,NLCEXP)
      WRITE (3,556)(ACCPVC(I),I=1,NLCEXP)
      WRITE (3,557)(ACCPPC(I),I=1,NLCEXP)
      WRITE (3,558)(ACCPYC(I),I=1,NLCEXP)
      WRITE (3,559)(ACCPSC(I),I=1,NLCEXP)
      WRITE (3,560)(ACCIPC(I),I=1,NLCEXP)
      WRITE (3,561)(ACCGFC(I),I=1,NLCEXP)
      WRITE (3,556)(ACCGVC(I),I=1,NLCEXP)
      WRITE (3,557)(ACCGPC(I),I=1,NLCEXP)
      WRITE (3,558)(ACCGYC(I),I=1,NLCEXP)
      WRITE (3,559)(ACCGSC(I),I=1,NLCEXP)
      WRITE (3,595)(ACCTPC(I),I=1,NLCEXP)
      WRITE(3,567)(ACCGTC(I),I=1,NLCEXP)
      WRITE(3,568)(ACCUSC(I),I=1,NLCEXP)
      WRITE(3,5681) (ACCUEC(I),I=1,NLCEXP)
      IF(NLCEXP-1) 643,643,642
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157

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  643 WRITE(3,570)(ACCPPR(I),I=1,NLCEXP)
      WRITE(3,571)(ACCAPR(I),I=1,NLCEXP)
      WRITE(3,674)
      WRITE(3,575)(I,I=1,NLCEXP)
      DO 645 I=1,NTOTAL
  645 WRITE(3,577) I,(ENAME(I,J),J=1,6),(RED(I,J),J=1,NLCEXP)
  650 FORMAT (1H1///37X,65HAGGREGATE LEAST-COST CURVE FOR REDUCTION OF H
     1UMAN EXPOSURE TO SO2)
  552 FORMAT (//10X,17HCALCULATION POINT,16X,10(3X,I2,4X))
  553 FORMAT (/10X,13HSO2 EMISSIONS/12X,17HPERCENT REDUCTION,14X,10(2X,F
     14,1, 3X))
 5531 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9,1)
  554 FORMAT (/10X,13HSO2 EXPOSURES/12X,17HPERCENT REDUCTION,14X,10(2X,F
     14,1,3X))
 5541 FORMAT (12X,18HABSOLUTE REDUCTION,3X,7H(P-PPM),10F9,1)
  555 FORMAT( /10X,13HPRIVATE COSTS /12X,5HFIXED,15X,8H($X1000),10F9.1)
  556 FORMAT(12X,8HVARIABLE,12X,8H($X1000),10F9,1)
  557 FORMAT( 12X,14HPROCESS CHANGE,5X,8H($X1000),10F9,1)
  558 FORMAT(12X,15HWASTE TREATMENT,5X,8H($X1000),10F9,1)
  559 FORMAT(12X,17HFUEL SUBSTITUTION,3X,8H($X1000),10F9,1)
  560 FORMAT (12X,18HTOTAL PRIVATE COST,2X,8H($X1000),10F9,1)
  595 FORMAT (12X,15HTOTAL GOVT COST,5X,8H($X1000),10F9.1)
  561 FORMAT( /10X,16HGOVERNMENT COSTS /12X,5HFIXED,15X,8H($X1000),10F9.
     11)
  567 FORMAT( /10X,16HGRAND TOTAL COST,6X,8H($X1000),10F9,1)
  568 FORMAT (/10X,29HUNIT PRIVATE COST OF REDUCING/12X,10HSO2 EMISNS,3X
     1,15H($X1000/GM/SEC),2X,9F9.3/)
 5681 FORMAT (12X,12HSO2 EXPOSURE,2X,14H($X1000/P-PPM),2X,9F9.3/)
  569 FORMAT(/10X,30HMARGINAL PRVT COST OF REDUCING/12X,10HSO2 EMISNS,3X
     1,15H($X1000/GM/SEC),5X,9F9,3)
 5691 FORMAT  (12X,12HSO2 EXPOSURE,2X,14H($X1000/P-PPM),5X,9F9.3/)
  570 FORMAT (/10X,18H[illegible]US REDUCTION IN/10X,21HPARTICULATE EMISSIONS/12
     1X,17HPERCENT REDUCTION,14X,10(2X,F4,1,3X))
  571 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9,1)
  674 FORMAT (1H1///36X,62HINDIVIDUAL EMISSION REDUCTION REQUIREMENT AT
     1EACH POINT ON THE/35X,55HAGGREGATE LEAST COST CURVE FOR REDUCTION
     2OF HUMAN EXPOSURE TO SO2/33X,68H(REQUIREMENT EXPRESSED AS PERCENT
     3OF TOTAL EMISSIONS OF EACH SOURCE)//79X,17HCOMPUTATION POINT)
  575 FORMAT (12X,6HSOURCE,15X,6HSOURCE/12X,6HNUMBER,16X,4HNAME,14X,
     110(3X,I2,3X)/)
  577 FORMAT (/14X,I2,8X,6A4,4X,10(2X,F4.1,2X))
  551 FORMAT (32X,19A4)
      RETURN
      END
      SUBROUTINE PHASE7(NTOTAL,METKEY,NRECEP,FIRST,DELTA,NLCPTS,NPTPTS,
     1EXTOT,PARTOT,SO2TOT,NEPPTS)
C
C PHASE VII
C
      COMMON/1/ ECCPFC(48,10),ECCPVC(48,10),ECCPWC(48,10),ECCPPC(48,10),
     1ECCPSC(48,10),ECCGFC(48,10),ECCGVC(48,10),ECCGWC(48,10),ECCGPC(48,
     210),ECCGSC(48,10),LEVECC(48,10,3),                 ECCTGC(48,10),ECCG
     3TC(48,10),ECCPSR(48,10),ECCASR(48,10),ECCUSC(48,10),ECCMSC(48,10),
     4ECCPER(48,10),ECCAER(48,10),ECCUEC(48,10),ECCMEC(48,10),ECCPPR(48,
     510),ECCPST(48,10),ECCPET(48,10),ECCPPT(48,10)
      COMMON/5/ RUNAME(10),FIXINC(3),OPRINC(3),              NTECH(48),
     1          POP(48),REDLC(10),REDPT(5) ,ENAME(48,6),
     2 PART(48),
     3     TNAME(48,5,6),NOPLEV(48,5),SREDUC(48,5,8),PREDUC(48,5,8),
     4 FIXCST(48,5,8),OPRCST(48,5,8),NTYPE(48,5),NCODE(48,5),
     5               FOX(3),OPR(3),PFCOST(    5,8),PVCOST(    5,8),
     6 GFCOST(    5,8),GVCOST(    5,8),PWCOST(    5,8),PSCOST(    5,8),
     7 PPCOST(    5,8),GWCOST(    5,8),GSCOST(    5,8),GPCOST(    5,8),AB(5)
     5,EXPOSE(48),CONCEN(48),NBIG(5),CONBIG(5),XBIG(5),YBIG(5),PER(5)
      COMMON/9/ CLOWER(48,10),LEVE(48),                NCUR(48),
     1          LOP(48,10,5),RCURVE(48,10),CCURVE(48,10),CLOW(48,10),
     2          LEVELP(48)
      COMMON NOGO(48,5,2),
     1       NCURVE(48), SCOEF(48,30), ECCTPC(48,10), ECCAPR(48,10),
     2       XRECEP(48), YRECEP(48), XSRC(48), YSRC(48), HEIGHT(48),
     3 GFACT(48), WIDTH(48), SO2(48)
      COMMON/4/ SAC(5,10),INDCTR(48,2,10),RED(48,10)
      COMMON/2/ INILEV(48,5)
      COMMON/3/ ACCPFC(10),ACCPVC(10),ACCPPC(10),ACCPWC(10),ACCPSC(10),
     1          ACCTPC(10),ACCGFC(10),ACCGVC(10),ACCGPC(10),ACCGWC(10),
     2          ACCGSC(10),ACCTGC(10),ACCGTC(10),ACCPSR(10),ACCASR(10),
     3          ACCAER(10),ACCUSC(10),ACCMSC(10),ACCUEC(10),ACCMEC(10),
     4          ACCPPR(10),ACCAPR(10),ACCPER(10)
      COMMON/7/ DATA(12,2,7)
      COMMON/20/  ENAM(3),RUNAM(10),PERCENTS(7)
  700 NEPPTS=0
      DO 702 I=1,NTOTAL
      LIM=NCURVE(I)
      K=IFIX(ECCPSR(I,LIM))/IFIX(DELTA)
      IF (K-NEPPTS) 702,702,701
  701 NEPPTS=K
  702 CONTINUE
      NEPPTS=NEPPTS+2
      DO 740 N=1,NEPPTS
      DO 707 I=1,NTOTAL
      LIM=NCURVE(I)
      DO 704 L=1,LIM
      IF (ECCPSR(I,L)-FLOAT(N-1)*DELTA) 704,705,705
  704 CONTINUE
      GO TO 706
  705 LEVE(I)=L
      GO TO 707
  706 LEVE(I)=NCURVE(I)
  707 CONTINUE
      ACCPFC(N)=0.0
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      ACCPVC(N)=0.0
      ACCPPC(N)=0.0
      ACCPMC(N)=0.0
      ACCPSC(N)=0.0
      ACCTPC(N)=0.0
      ACCGFC(N)=0.0
      ACCGVC(N)=0.0
      ACCGPC(N)=0.0
      ACCGMC(N)=0.0
      ACCGSC(N)=0.0
      ACCTGC(N)=0.0
      ACCGTC(N)=0.0
      ACCASR(N)=0.0
      ACCAER(N)=0.0
      ACCAPR(N)=0.0
      DO 710 I=1,NTOTAL
      L=LEVE(I)
      RED(I,N)=ECCPSR(I,L)
      ACCPFC(N)=ACCPFC(N)+ECCPFC(I,L)
      ACCPVC(N)=ACCPVC(N)+ECCPVC(I,L)
      ACCPPC(N)=ACCPPC(N)+ECCPPC(I,L)
      ACCPMC(N)=ACCPMC(N)+ECCPMC(I,L)
      ACCPSC(N)=ACCPSC(N)+ECCPSC(I,L)
      ACCTPC(N)=ACCTPC(N)+ECCTPC(I,L)
      ACCGFC(N)=ACCGFC(N)+ECCGFC(I,L)
      ACCGVC(N)=ACCGVC(N)+ECCGVC(I,L)
      ACCGPC(N)=ACCGPC(N)+ECCGPC(I,L)
      ACCGMC(N)=ACCGMC(N)+ECCGMC(I,L)
      ACCGSC(N)=ACCGSC(N)+ECCGSC(I,L)
      ACCTGC(N)=ACCTGC(N)+ECCTGC(I,L)
      ACCGTC(N)=ACCGTC(N)+ECCGTC(I,L)
      ACCASR(N)=ACCASR(N)+ECCASR(I,L)
      ACCAER(N)=ACCAER(N)+ECCAER(I,L)
  710 ACCAPR(N)=ACCAPR(N)+ECCAPR(I,L)
      ACCPSR(N)=ACCASR(N)/POPTOT*100.0
      ACCPER(N)=ACCAER(N)/EXTOT*100.0
      ACCPPR(N)=ACCAPR(N)/PARTOT*100.0
      IF (ACCASR(N)) 731,731,732
  731 ACCUSC(N)=0.0
      ACCUEC(N)=0.0
      GO TO 708
  732 ACCUSC(N)=ACCTPC(N)/ACCASR(N)
      ACCUEC(N)=ACCTPC(N)/ACCAER(N)
  708 IF (N-1)  711,711,703
  703 IF (ACCASR(N)-ACCASR(N-1)) 711,711,712
  711 ACCMSC(N)=0.0
      ACCMEC(N)=0.0
      GO TO 713
  712 ACCMSC(N)=(ACCTPC(N)-ACCTPC(N-1))/(ACCASR(N)-ACCASR(N-1))
      ACCMEC(N)=(ACCTPC(N)-ACCTPC(N-1))/(ACCAER(N)-ACCAER(N-1))
  713 DO 717 I=1,NTOTAL
      CALL PHASE2 (I)
      L=LEVE(I)
      LIM=NTECH(I)
      DO 714 J=1,LIM
  714 INILEV(I,J)=LEVECC(I,L,J)
      FIRST=ECCPPR(I,L)
      CALL COST (I,FIRST,DELTA,NTECH,NOPLEV,PFCOST,NCOUE,PVCOST,PREDUC,
     1NCUR,LOP,RCURVE,CCURVE,IPILEV)
      LIM=NCUR(I)
      DO 715 J=1,LIM
  715 RCURVE(I,J)=RCURVE(I,J)*PART(I)
  717 CALL ENVLPE (I,CCURVE,NCUR,RCURVE,CLOW)
      DO 730 M=1,NPTPTS
      IF (RENPT(M)-ACCPPR(N))718,718,720
  718 SAC(M,N)=0.0
      DO 719 I=1,NTOTAL
      L=LEVE(I)
      INDCTR(I,M,N)=0
      LIM=NTECH(I)
      DO 719 J=1,LIM
  719 INDCTR(I,M,N)=INDCTR(I,M,N)+LEVECC(I,L,J)*10**(J-1)
      GO TO 730
  720 OBJ=RENPT(M)*PARTOT/100.0
      CALL SOLUTN(NTOTAL,OBJ,NCUR,CLOW,RCURVE,LEVELP,LTEST)
      IF (LTEST) 723,723,721
  721 LIM=NPTPTS-M+1
      DO 722 J=1,LIM
      L=M+J-1
      SAC(M,N)=-5.0
      DO 722 I=1,NTOTAL
  722 INDCTR(I,L,N)=0
      GO TO 740
  723 SAC(M,N)=0.0
      DO 725 I=1,NTOTAL
      INDCTR(I,M,N)=0
      K=LEVELP(I)
      SAC(M,N)=SAC(M,N)+CCURVE(I,K)
      LIM=NTECH(I)
      DO 724 J=1,LIM
  724 INDCTR(I,M,N)=INDCTR(I,M,N)+LOP(I,K,J)*10**(J-1)
  725 CONTINUE
      SAC(M,N)=SAC(M,N)-ACCTPC(N)
  730 CONTINUE
  740 CONTINUE
  741 WRITE (3,750)
      NPOINTS=NEPPTS
      DO 6401 J=1,NPOINTS
      DATA(J,1,1)=DATA(J,1,2)=ACCPSR(J)
      DATA(J,2,1)=ACCTPC(J)  $  DATA(J,2,2)=ACCGTC(J)
 6401 CONTINUE
      CALL PLTS(RUNAM , DATA,NPOINTS)
      WRITE (3,551)(RUNAME(I),I=1,19)
      WRITE (3,552)(I,I=1,NEPPTS)
      WRITE (3,553)(ACCPSR(I),I=1,NEPPTS)
      WRITE(3,5531) (ACCASR(I),I=1,NEPPTS)
      WRITE (3,554)(ACCPER(I),I=1,NEPPTS)
      WRITE(3,5541) (ACCAER(I),I=1,NEPPTS)
      WRITE (3,555)(ACCPFC(I),I=1,NEPPTS)
      WRITE (3,556)(ACCPVC(I),I=1,NEPPTS)
      WRITE (3,557)(ACCPPC(I),I=1,NEPPTS)
      WRITE (3,558) (ACCPWC(I),I=1,NEPPTS)
      WRITE (3,559) (ACCPSC(I),I=1,NEPPTS)
      WRITE (3,560) (ACCTPC(I),I=1,NEPPTS)
      WRITE (3,561) (ACCGFC(I),I=1,NEPPTS)
      WRITE (3,556) (ACCGVC(I),I=1,NEPPTS)
      WRITE (3,557) (ACCGPC(I),I=1,NEPPTS)
      WRITE (3,558) (ACCGWC(I),I=1,NEPPTS)
      WRITE (3,559) (ACCGSC(I),I=1,NEPPTS)
      WRITE (3,595) (ACCTGC(I),I=1,NEPPTS)
      WRITE (3,567) (ACCGTC(I),I=1,NEPPTS)
      WRITE (3,568) (ACCUSC(I),I=1,NEPPTS)
      WRITE(3,5681) (ACCUEC(I),I=1,NEPPTS)
      IF (NEPPTS-1) 743,743,742
  742 WRITE (3,569) (ACCMSC(I),I=2,NEPPTS)
      WRITE(3,5691) (ACCMEC(I),I=2,NEPPTS)
  743 WRITE (3,570) (ACCPPR(I),I=1,NEPPTS)
      WRITE (3,571) (ACCAPR(I),I=1,NEPPTS)
      WRITE (3,774)
      WRITE (3,575)(I,I=1,NEPPTS)
      DO 745 I=1,NTOTAL
      WRITE (3,577)I,(ENAME(I,J),J=1,6),(RED(I,J),J=1,NEPPTS)
      DO 745 M=1,NPTPTS
      PERCENTS(M)=REDPT(M)
  745 WRITE(3,578) REDPT(M),(INDCTR(I,M,N),N=1,NEPPTS)
      NOLINES=NPTPTS
      CALL PLT7(RUNAM ,PERCENTS,NOLINES)
  750 FORMAT(1H1///18X,104HAGGREGATE EQUAL-PROPORTIONAL CURVE FOR REDUCT
     1ION OF SO2 EMISSIONS AND REDUCTION OF HUMAN EXPOSURE TO SO2)
  552 FORMAT (//10X,17HCALCULATION POINT,16X,10(3X,I2,4X))
  553 FORMAT (/10X,13HSO2 EMISSIONS/12X,17HPERCENT REDUCTION,14X,10(2X,F
     14.1, 3X))
 5531 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9,1)
  554 FORMAT (/10X,13HSO2 EXPOSURES/12X,17HPERCENT REDUCTION,14X,10(2X,F
     14,1,3X))
 5541 FORMAT (12X,18HABSOLUTE REDUCTION,3X,7H(P-PPM),10F9,1)
  555 FORMAT( /10X,13HPRIVATE COSTS /12X,5HFIXED,15X,8H($X1000),10F9.1)
  556 FORMAT(12X,6HVARIABLE,12X,8H($X1000),10F9,1)
  557 FORMAT( 12X,14HPROCESS CHANGE,6X,8H($X1000),10F9,1)
  558 FORMAT(12X,15HWASTE TREATMENT,5X,8H($X1000),10F9,1)
  559 FORMAT(12X,17HFUEL SUBSTITUTION,3X,8H($X1000),10F9,1)
  560 FORMAT (12X,18HTOTAL PRIVATE COST,2X,8H($X1000),10F9,1)
  595 FORMAT (12X,15HTOTAL GOVT COST,5X,8H($X1000),10F9,1)
  561 FORMAT( /10X,16HGOVERNMENT COSTS /12X,5HFIXED,15X,8H($X1000),10F9,
     11)
  567 FORMAT( /10X,16HGRAND TOTAL COST,6X,8H($X1000),10F9,1)
  568 FORMAT (/10X,29HUNIT PRIVATE COST OF REDUCING/12X,10HSO2 EMISNS,3X
     1,15H($X1000/GM/SEC),2X,9F9.3/)
 5681 FORMAT (12X,12HSO2 EXPOSURE,2X,14H($X1000/P-PPM),2X,9F9.3/)
  569 FORMAT(/10X,30HMARGINAL PRVT COST OF REDUCING/12X,10HSO2 EMISNS,3X
     1,15H($X1000/GM/SEC),5X,9F9.3)
 5691 FORMAT  (12X,12HSO2 EXPOSURE,2X,14H($X1000/P-PPM),5X,9F9.3/)
  570 FORMAT (/10X,18HBONUS REDUCTION IN/10X,21HPARTICULATE EMISSIONS/12
     1X,17HPERCENT REDUCTION,14X,10(2X,F4.1,3X))
  571 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9,1)
  774 FORMAT (1H1///36X,62HINDIVIDUAL EMISSION REDUCTION REQUIREMENT AT
     1EACH POINT ON THE/18X,104HAGGREGATE EQUAL-PROPORTIONAL CURVE FOR R
     2EDUCTION OF SO2 EMISSIONS AND REDUCTION OF HUMAN EXPOSURE TO SO2/3
     33X,68H(REQUIREMENT EXPRESSED AS PERCENT OF TOTAL EMISSIONS OF EACH
     4 SOURCE)//79X,17HCOMPUTATION POINT)
 SUBROUTINE PCC(NPIPIS,NIX,NTOTAL,SO2TOT,EXTOT,PARTOT)
 COMMON/1/ ECCPFC(48,10),ECCPVC(48,10),ECCPWC(48,10),ECCPPC(48,10),
1ECCPSC(48,10),ECCGFC(48,10),ECCGVC(48,10),ECCGWC(48,10),ECCGPC(48,
210),ECCGSC(48,10),LEVECC(48,10,8),                ECCIGC(48,10),ECCG
3TC(48,10),ECCPSR(48,10),ECCASR(48,10),ECCUSC(48,10),ECCMSC(48,10),
4ECCPER(48,10),ECCAER(48,10),ECCUEC(48,10),ECCMEC(48,10),ECCPPR(48,
510),ECCPST(48,10),ECCPET(48,10),ECCPPT(48,10)
 COMMON/5/ RUNAME(10),FIXINC(3),OPRINC(3),              NTECH(48),
1             POP(48),PEBLC(10),REPPT(2) ,ENAME(48,6),
2 PART(48),
3     TNAME(48,5,6),YOPLEV(48,5),SREDUC(48,5,8),PREDUC(48,5,8),
4 FIXCST(48,5,8),OPRCST(48,5,8),NTYPE(48,5),NCODE(48,5),
5              FOX(3),OPR(3),PFCOST(   5,8),PVCOST(   5,8),
6 GFCOST(   5,8),GVCOST(   5,8),PWCOST(   5,8),PSCOST(   5,8),
7 PPCOST(   5,8),GWCOST(   5,8),GSCOST(   5,8),GPCOST(   5,8),AB(5)
8,EXPOSE(48),CONCEN(48),NBIG(5),CONBIG(5),XBIG(5),YBIG(5),PER(5)
 COMMON/9/ CLOWER(48,10),LEVE(48),              NCUR(48),
1         IOP(48,10,8),RCURVE(48,10),CCURVE(48,10),CLOW(48,10),
2         LEVELP(48)
 COMMON NOGO(48,2,5),
1        NCURVE(48), SCOEF(48,30), ECCTPC(48,10), ECCAPR(48,10),
2        XRECEP(48), YRECEP(48), XSRC(48), YSRC(48), HEIGHT(48),
3 GFACT(48), WIDTH(48), SO2(48)
 COMMON/4/ SAC(5,10),INDCTR(48,5,10),RED(48,10)
 COMMON/2/ INILEV(48,5)
 COMMON/3/ ACCPFC(10),ACCPVC(10),ACCPPC(10),ACCPWC(10),ACCPSC(10),
1         ACCTPC(10),ACCGFC(10),ACCGVC(10),ACCGPC(10),ACCGWC(10),
2         ACCGSC(10),ACCIGC(10),ACCGTC(10),ACCPSR(10),ACCASR(10),
3         ACCAER(10),ACCUSC(10),ACCMSC(10),ACCUEC(10),ACCMEC(10),
4         ACCPPR(10),ACCAPR(10),ACCPER(10)
 COMMON/7/ DATA(12,2,7)
 COMMON/21/  ENAM(3),RUNAM(10),PERCENTS(7)
 DIMENSION PCCPSR(10),PCCASR(10),PCCPER(10),PCCAER(10),PCCPFC(10),
1         PCCPVC(10),PCCPPC(10),PCCPWC(10),PCCPSC(10),PCCTPC(10),
2         PCCGFC(10),PCCGVC(10),PCCGPC(10),PCCGWC(10),PCCGSC(10),
3         PCCIGC(10),PCCGTC(10),PCCPPR(10),PCCAPR(10)
 DO 590 M=1,NPIPIS
 DO 579 N=1,NIX
 PCCPSR(N)  =PCCASR(N)  =PCCPER(N)  =PCCAER(N)  =PCCPFC(N)  =0.0
 PCCPVC(N)  =PCCPPC(N)  =PCCPWC(N)  =PCCPSC(N)  =PCCTPC(N)  =0.0
 PCCGFC(N)  =PCCGVC(N)  =PCCGPC(N)  =PCCGWC(N)  =PCCGSC(N)  =0.0
 PCCTGC(N)  =PCCGTC(N)  =PCCPPR(N)  =PCCAPR(N) = 0.0
 DO 350 I=1,NTOTAL
 CALL PHASE2(I)
 KD = INDCTR(I,M,N)
 NN = NTECH(I)
 DO 310 J=1,NN
 KT = KD/10
 K = KD - 10*KT
 PCCPVC(N)    = PCCPVC(N)    + PVCOST(   J,K)
 PCCPWC(N)    = PCCPWC(N)    + PWCOST(   J,K)
 PCCPPC(N)    = PCCPPC(N)    + PPCOST(   J,K)
 PCCPSC(N)    = PCCPSC(N)    + PSCOST(   J,K)
 PCCGFC(N)    = PCCGFC(N)    + GFCOST(   J,K)
 PCCGVC(N)    = PCCGVC(N)    + GVCOST(   J,K)
 PCCGWC(N)    = PCCGWC(N)    + GWCOST(   J,K)
 PCCGPC(N)    = PCCGPC(N)    + GPCOST(   J,K)
 PCCGSC(N)    = PCCGSC(N)    + GSCOST(   J,K)
 PCCPFC(N)    = PCCPFC(N)    + PFCOST(   J,K)
```

```
      IF (K-1) 301,310,301
  301 IF (NCODE(I,J)-10) 302,304,304
  302 PCCPSR(N)    = PCCPSR(N)    + SREDUC(I,J,K)
      PCCPPR(N)    = PCCPPR(N)    + PREDUC(I,J,K)
      GO TO 310
  304 PCCPSR(N)    = PCCPSR(N)   +(100,0-PCCPSR(N)) * SREDUC(I,J,K)/100,0
      PCCPPR(N)    = PCCPPR(N)   +(100,0-PCCPPR(N)) * PREDUC(I,J,K)/100,0
  310 KO=KT
      PCCTPC(N)    = PCCPVC(N)    + PCCPFC(N)
      PCCTGC(N)    = PCCGVC(N)    + PCCGFC(N)
      PCCGTC(N)    = PCCTPC(N)    + PCCTGC(N)
      PCCAPR(N) = PCCAPR(N) + PCCPPR(N)*PART(I)/100,0
      PCCASR(N) = PCCASR(N) + PCCPSR(N)*S02(I)/100,0
      PCCAER(N) = PCCAER(N) + PCCPSR(N)*EXPOSE(I)/100,0
      PCCPSR(N) = PCCPPR(N) = 0,0
  350 CONTINUE
      PCCPSR(N) = 100,0*(PCCASR(N)/S02TOT)
      PCCPER(N) = 100,0*(PCCAER(N)/EXTOT)
      PCCPPR(N) = 100,0*(PCCAPR(N)/PARTOT)
  579 CONTINUE
      NPOINTS=NIX
      NOLINES=NPTPTS
      DO 1000 I=1,NIX
      DATA(I,1,M)=PCCPSR(I)  $  DATA(I,2,M)=PCCTPC(I)
 1000 CONTINUE
      DO 1001 I1=1,NIX
      DATA(I1,1,M)=PCCPSR(I1)  $  DATA(I1,2,M)=PCCGTC(I1)
 1001 CONTINUE
      WRITE ( 3,581) REDPT(M)
  581 FORMAT (1H1///32X,    *AGGREGATE COST CURVE FOR NOMINAL PARTICULATE
     1 REDUCTION OF*,F5,1, * PERCENT*)
      WRITE(3,552) (I,I=1,NIX)
      WRITE(3,553) (PCCPSR(I),I=1,NIX)
      WRITE(3,5531) (PCCASR(I),I=1,NIX)
      WRITE(3,554) (PCCPER(I),I=1,NIX)
      WRITE(3,5541) (PCCAER(I),I=1,NIX)
      WRITE(3,555) (PCCPFC(I),I=1,NIX)
      WRITE(3,556) (PCCPVC(I),I=1,NIX)
      WRITE(3,557) (PCCPPC(I),I=1,NIX)
      WRITE(3,558) (PCCPMC(I),I=1,NIX)
      WRITE(3,559) (PCCPSC(I),I=1,NIX)
      WRITE(3,560) (PCCTPC(I),I=1,NIX)
      WRITE(3,561) (PCCGFC(I),I=1,NIX)
      WRITE(3,556) (PCCGVC(I),I=1,NIX)
      WRITE(3,557) (PCCGFC(I),I=1,NIX)
      WRITE(3,558) (PCCGMC(I),I=1,NIX)
      WRITE(3,559) (PCCGSC(I),I=1,NIX)
      WRITE(3,595) (PCCTGC(I),I=1,NIX)
      WRITE(3,557) (PCCGTC(I),I=1,NIX)
      WRITE(3,570) (PCCPPR(I),I=1,NIX)
      WRITE(3,571) (PCCAPR(I),I=1,NIX)
  551 FORMAT (32X,    1944    )
  552 FORMAT (//10X,17HCALCULATION POINT,16X,10(3X,I2,4X))
  553 FORMAT (/10X,13HSO2 EMISSIONS/12X,17HPERCENT REDUCTION,14X,10(2X,F
    14,1, 3X))
5531 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9,1)
 554 FORMAT (/10X,13HSO2 EXPOSURES/12X,17HPERCENT REDUCTION,14X,10(2X,F
    14,1,3X))
5541 FORMAT (12X,18HABSOLUTE REDUCTION,3X,7H(P-PPM),10F9.1)
 555 FORMAT( /10X,13HPRIVATE COSTS /12X,5HFIXED,15X,8H($X1000),10F9.1)
 556 FORMAT(12X,8HVARIABLE,12X,8H($X1000),10F9,1)
 557 FORMAT( 12X,14HPROCESS CHANGE,6X,8H($X1000),10F9,1)
 558 FORMAT(12X,15HWASTE TREATMENT,5X,8H($X1000),10F9,1)
 559 FORMAT(12X,17HFUEL SUBSTITUTION,3X,8H($X1000),10F9.1)
 560 FORMAT (12X,18HTOTAL PRIVATE COST,2X,8H($X1000),10F9.1)
 595 FORMAT (12X,15HTOTAL GOVT COST,5X,8H($X1000),10F9.1)
 561 FORMAT( /10X,16HGOVERNMENT COSTS /12X,5HFIXED,15X,8H($X1000),10F9.
    11)
 567 FORMAT( /10X,16HGRAND TOTAL COST,6X,8H($X1000),10F9,1)
 570 FORMAT (                              /10X,21HPARTICULATE EMISSIONS/12
    1X,17HPERCENT REDUCTION,14X,10(2X,F4,1,3X))
 571 FORMAT (12X,18HABSOLUTE REDUCTION,1X,9H(GMS/SEC),10F9,1)
 500 CONTINUE
     CALL PLT4 (RUNAD ,DATA,NPOINTS,NOLINES)
     CALL PLT5 (RUNAD ,DATA,NPOINTS,NOLINES)
     RETURN
     END
```

```
      SUBROUTINE COST (I,FIRST,DELTA,NTECH,NOPLEV,FCOST,NCODE,VCOST,
     1                 REDCTN,NCURVE,LEVRED,REDPER,CCURVE,INILEV)
C
C ARRAY VARIABLES REQUIRED
C
      DIMENSION NTECH(48), NOPLEV(48,5),FCOST(    5,8),NCODE(48,5),
     1          VCOST(    5,8),REDCTN(48,5,8),INILEV(48,5)
      COMMON NOGO(48,5,5)
C
C ARRAY VARIABLES RETURNED
C
      DIMENSION NCURVE(48)
      DIMENSION            LEVRED(48,10,8),REDPER(48,10),CCURVE(48,10)
C
C INTERNAL ARRAY VARIABLES
C
      DIMENSION REDLEV(10),INDEX(500),SO2R(500),CTOT(500),LEV(5),
     1          LEAST (10)
      L=NTECH(I)
      IF (NTECH(I)) 141,135,141
  135 NCURVE(I)=1
      GO TO 181
  141 IF (NTECH(I)-5) 142,150,150
  142 N=5-NTECH(I)
       DO 143 J=1,N
       K=NTECH(I)+J
        NCODE(I,K)=1
      INILEV(I,K)=1
  143 NOPLEV(I,K)=1
  150 NUM=0
       NOP1=NOPLEV(I,1)                                                 AIRPL
        NOP2=NOPLEV(I,2)                                                AIRPL
         NOP3=NOPLEV(I,3)                                               AIRPL
          NOP4=NOPLEV(I,4)                                              AIRPL
           NOP5=NOPLEV(I,5)                                             AIRPL
      LOW1=INILEV(I,1)
      LOW2=INILEV(I,2)
      LOW3=INILEV(I,3)
      LOW4=INILEV(I,4)
      LOW5=INILEV(I,5)
       DO 160 J1=LOW1,NOP1
        LEV(1)=J1                                                       AIRPL
        DO 160 J2=LOW2,NOP2
         LEV(2)=J2                                                      AIRPL
         DO 160 J3=LOW3,NOP3
          LEV(3)=J3                                                     AIRPL
          DO 160 J4=LOW4,NOP4
           LEV(4)=J4                                                    AIRPL
           DO 160 J5=LOW5,NOP5
            LEV(5)=J5                                                   AIRPL
      L=NTECH(I)
      DO 153 J=1,L
      DO 153 K=1,J
      IF ((LEV(J)-1)*(LEV(K)-1)*NOGO(I,J,K)) 153,153,160
  153 CONTINUE
            NUM=NUM+1
            INDEX(NUM)=0
```

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```
          SO2R(NUM)=0.0
          CTOT(NUM)=0.0
           DO 159 J=1,5
            K=LEV(J)
      IF (K-1) 144,159,144
  144 CTOT(NUM)=CTOT(NUM)+FCOST(  J,K)+VCOST(  J,K)
      IF (MCODE(I,J)-10)154,157,157
  154 SO2R(NUM)=SO2R(NUM)+REDCTN(I,J,K)/100.0
            GO TO 159
  157 SO2R(NUM)=SO2R(NUM)+(1.0-SO2R(NUM))*REDCTN(I,J,K)/100.0
  159       INDEX(NUM)=INDEX(NUM)+K*10**(J-1)
  160   CONTINUE
      J=1
      REDLEV(J)=FIRST
  161 LEAST(J)=0
        A=1000000000.0
        DO 165 K=1,NUM
        IF(CTOT(K)-A)163,163,165
  163   IF(SO2R(K)-REDLEV(J)/100.0)165,164,164
  164    LEAST(J)=K
        A=CTOT(K)
  165    CONTINUE
      IF (J-1) 167,167,162
  162 IF (LEAST(J)-LEAST(J-1) ) 167,166,167
  166 REDLEV(J-1)=REDLEV(J)
      J=J-1
  167  IF(LEAST(J)-0)170,171,170
  170 J=J+1
      REDLEV(J)=REDLEV(J-1)+DELTA
      IF (REDLEV(J)-100.0) 161,171,171
  171 NCURVE(I)=J
  173  L=NCURVE(I)
      LEAST(L)=0
      A=0.0
      B=0.0
      DO 175 J=1,NUM
      IF (A-SO2R(J)) 175,174,176
  174 IF (B-CTOT(J)) 176,175,175
  175 LEAST(L)=J
      A=SO2R(J)
      B=CTOT(J)
  176 CONTINUE
      IF(LEAST(L))136,136,177
  136 NCURVE(I)=1
      GO TO 179
  177 M=L-1
      M1=LEAST(L)
      M2=LEAST(M)
      IF (SO2R(M1)-SO2R(M2)) 178,178,179
  178 NCURVE(I)=NCURVE(I)-1
  179 L=NCURVE(I)
      M=NTECH(I)
      DO 180 J=1,L
      N=LEAST(J)
      REOPER(I,J)=SO2R(N)
      COURVE(I,J)=CTOT(N)
      ITEMP=INDEX(N)
      DO 180 K=1,M
      JTEMP=ITEMP/10
      LEVRED(I,J,K)=ITEMP-JTEMP*10
  180 ITEMP=JTEMP
  181 CONTINUE
  182 RETURN
      END
      SUBROUTINE ENVLPE (I,CCURVE,NCURVE,REDABS,CLOWER)
      DIMENSION CCURVE(46,10), NCURVE(46),REDABS(46,10),CLOWER(46,10)
       CLOWER(I,1)=CCURVE(I,1)
       L=1
206    IF(L-NCURVE(I))207,212,215
207    M=L+1
       N=NCURVE(I)
       SMALL=(CCURVE(I,M)-CCURVE(I,L))/(REDABS(I,M)-REDABS(I,L))
       DO 210  J=M,N
        SLOPE=(CCURVE(I,J)-CCURVE(I,L))/(REDABS(I,J)-REDABS(I,L))
        IF(SLOPE-SMALL)209,209,210
209     SMALL=SLOPE
        LOWEST=J
210     CONTINUE
       DO 211  J=M,LOWEST
211     CLOWER(I,J)=CLOWER(I,L)+(REDABS(I,J)-REDABS(I,L))*SMALL
       L=LOWEST
       GO TO 206
215   RETURN
      END
```

169

```
      SUBROUTINE SOLUTN(NTOTAL,ABSOBJ,NCURVE,CLOWER,REDABS,LEVRED,LRTEST
     1)
      DIMENSION NCURVE(48),CLOWER(48,10),REDABS(48,10),LEVRED(48)
      DO 216 I=1,NTOTAL
  216 LEVRED(I)=1
      LRTEST=0
      RED=1.0
      DO 217 I=1,NTOTAL
  217 RED=RED*REDABS(I,1)
  218 IF(RED-ABSOBJ)219,230,230
  219 A=1000000000.0
      NEXT=0
      DO 220 I=1,NTOTAL
       L=LEVRED(I)
       M=L+1
      IF(L-NCURVE(I))221,220,220
  221  SLOPE=(CLOWER(I,M)-CLOWER(I,L))/(REDABS(I,M)-REDABS(I,L))
      IF(SLOPE-A)222,220,220
  222  NEXT=I
       A=SLOPE
  220 CONTINUE
  224 IF(NEXT)225,226,225
  225 L=LEVRED(NEXT)
      M=L+1
      RED=RED+(REDABS(NEXT,M)-REDABS(NEXT,L))
      LEVRED(NEXT)=LEVRED(NEXT)+1
      GO TO 218
  226 LRTEST=1
  230 RETURN
      END
      SUBROUTINE LPUNCH (NTOTAL,NRECEP,CONCST)
      COMMON NOSO(48,5,5),
     1       NCURVE(48), SCOEF(48,30), ECCTPC(48,10), ECCAPR(48,10),
     2       XRECEP(48), YRECEP(48), XSRC(48), YSRC(48), HEIGHT(48),
     3 GFACT(48), WIDTH(48), SO2(48)
      COMMON/1/ ECCPFC(48,10),ECCPVC(48,10),ECCPWC(48,10),ECCPPC(48,10),
     1ECCPSC(48,10),ECCGFC(48,10),ECCGVC(48,10),ECCGWC(48,10),ECCGPC(48,
     210),ECCGSC(48,10),LEVECC(48,10,8),              ECCTGC(48,10),ECCG
     3TC(48,10),ECCPSR(48,10),ECCASR(48,10)
      DIMENSION CONCST(48,10)
      WRITE (47,800)
  800 FORMAT (      *ROW ID*/       5X,*1*,5X,*0CSTROW*)
      DO 801 I = 1, NTOTAL
  801 WRITE (47,802) I
  802 FORMAT (          5X,*1*,5X,*0SRC*,I3)
      DO 803 M = 1, NRECEP
  803 WRITE (47,804) M
  804 FORMAT (          5X,*1*,5X,*+REC*,I3)
      WRITE (47,805)
  805 FORMAT (               *MATRIX*)
      DO 807 I = 1,NTOTAL
      KK = NCURVE(I)
      DO 807 K=1,KK
      WRITE (47,810) I, K,               CONCST(I,K)
  810 FORMAT (      5X,*1L*,I3,I2,*CSTROW*,E12.4)
      DO 809 M=1,NRECEP
      TEMP4 = SCOEF(I,M)*(SO2(I) - ECCASR(I,K))
  809 WRITE (47,808) I, K, M,             TEMP4
  808 FORMAT(       5X,*1L*,I3,I2,*REC*,I3,E12.4)
  807 WRITE (47,806) I,K,I
  806 FORMAT(       5X,*1L*,I3,I2,*SRC*,I3,9X,*1.0*)
      ENDFILE 47
      DO 813 KJ=1,2
      WRITE ( 7,815)
  815 FORMAT (            3HRHS)
      DO 811  I=1,NTOTAL
  811 WRITE ( 7,812) I
  812 FORMAT(       5X,*1*,6X,*SRC*,I3,9X,*1.0*)
      DO 813 M=1,NRECEP
  813 WRITE ( 7,814) M
  814 FORMAT (      5X,*1*,6X,*REC*,I3)
      WRITE ( 7,820)
  820 FORMAT (*EOF*)
      RETURN
      END
```

```
SUBROUTINE PLT4(RUNAME,DATA,NPOINT,NLINE)
COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
DIMENSION DATA (12,2,7)
CALL INIT
CALL SYMBOL(4,25-9.*CHAR,   9.,SIZE,18HTOTAL PRIVATE COST, 0.,18)
CALL SYMBOL(4,25-40,*CHAR,9,-SPACE,SIZE,RUNAME,0.,80)
CALL CHART(DATA,NPOINT,NLINE)
RETURN
END
```

```
SUBROUTINE PLT5(RUNAME,DATA,NPOINT,NLINE)
COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
DIMENSION DATA (12,2,7)
CALL INIT
CALL SYMBOL(4,25-8.*CHAR,   9.,SIZE,16HGRAND TOTAL COST, 0.,16)
CALL SYMBOL(4,25-40,*CHAR,9,-SPACE,SIZE,RUNAME,0.,80)
CALL CHART(DATA,NPOINT,NLINE)
RETURN
END
```

```
 SUBROUTINE PLT6(RUNAME,DATA,NPOINT)
 COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
 DIMENSION DATA (12,2,7)
 CALL INIT
 CALL SYMBOL(4,25-14,5*CHAR,9,      ,SIZE,
*   29HAGGREGATE LEAST COST EXPOSURE, 0., 29)
 CALL SYMBOL(4,25-8.*CHAR,9,-SPACE,SIZE,16HREDUCTION CURVES,0.,16)
 CALL SYMBOL(4,25-40,*CHAR,9,-2,*SPACE,SIZE,RUNAME,0.,80)
 CALL SYMBOL(4,25-11,*CHAR+,05, 9,-3,*SPACE+,05, .10,
*  JSYMBL(1),0.,-1)
 CALL SYMBOL(4,25-7.*CHAR, 9,-3,*SPACE, SIZE,
*  18HTOTAL PRIVATE COST,0.,18)
 CALL SYMBOL(4,25-11,*CHAR+,05, 9.05-4,*SPACE, .10, JSYMBL(2),
*  0., -1)
 CALL SYMBOL(4,25- 7,*CHAR,9,-4,*SPACE;SIZE,
*  16HGRAND TOTAL COST,0.,16)
 CALL CHART(DATA,NPOINT,2)
 RETURN
 END
```

```
      SUBROUTINE PLT7(RUNAME,DATA,N)
      COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
      DIMENSION DATA(7)
      CALL INIT
      CALL SYMBOL(4,25-13,*CHAR, 7,,SIZE,
     *  26HAGGREGATE EQUIPROPORTIONAL, 0., 26)
      CALL SYMBOL(4,25-5.5*CHAR, 7.-SPACE,SIZE,
     *  11HCOST CURVES, 0.,11)
      CALL SYMBOL(4,25-40,*CHAR, 7,-2,*SPACE,SIZE,RUNAME, 0.,80)
      CALL PRCENTS(DATA,N)
      RETURN
      END
```

```
      SUBROUTINE BOX(XDELT ,YDELT ,NPWR)
      COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
      JXDEL = XDELT
      JYDEL = YDELT
C *** DRAW THE BOX
      CALL PLOT(X0+5.,Y0+5.,3)
      CALL PLOT(X0,Y0+5.,2)
      CALL PLOT(X0,Y0,1)
      CALL PLOT(X0+5.,Y0.1)
      CALL PLOT(X0+5.,Y0+5.,1)
C *** LABEL THE X-AXIS + INSERT TICK MARKS
      X=X0+2,5- (15./2.)*CHAR
      CALL SYMBOL(X + .05, Y0 - .40, .10, 16, 0., -1)
      CALL SYMBOL(X+2,*CHAR, Y0-,45, SIZE, 2HSQ, 0., 2)
      CALL SYMBOL(X+4,*CHAR,Y0-,502,SIZE,1H2, 0.,1)
      CALL SYMBOL(X+6,*CHAR,Y0-.45,SIZE,9HREDUCTION, 0.,9)
      DO 30 I=1,5
      IF(I.EQ,5) GO TO 29
      CALL PLOT (X0+I, Y0+,1, 3)
      CALL PLOT(X0+I, Y0      ,2)
29    CALL NUMBER(X0+I-2.*CHAR,Y0-,16,SIZE,JXDEL*I,0.,2HI3)
30    CONTINUE
C *** LABEL THE Y-AXIS + INSERT TICK MARKS
      CALL SYMBOL(X0-(NPWR+3)*CHAR,Y0+2,5-6,5*CHAR,SIZE,
     *13HCOST ($*1000),90.,13)
      DO 60 I=1,5
      CALL NUMBER (X0-7.*CHAR,Y0+I-,5*SIZE,SIZE,JYDEL*I,0.,2HI6)
      IF(I.EQ,5) GO TO 60
      CALL PLOT (X0,Y0+I,3)
      CALL PLOT (X0+,1,Y0+I,2)
60    CONTINUE
C *** LABEL THE Y=AXIS
      RETURN
      END
```

173

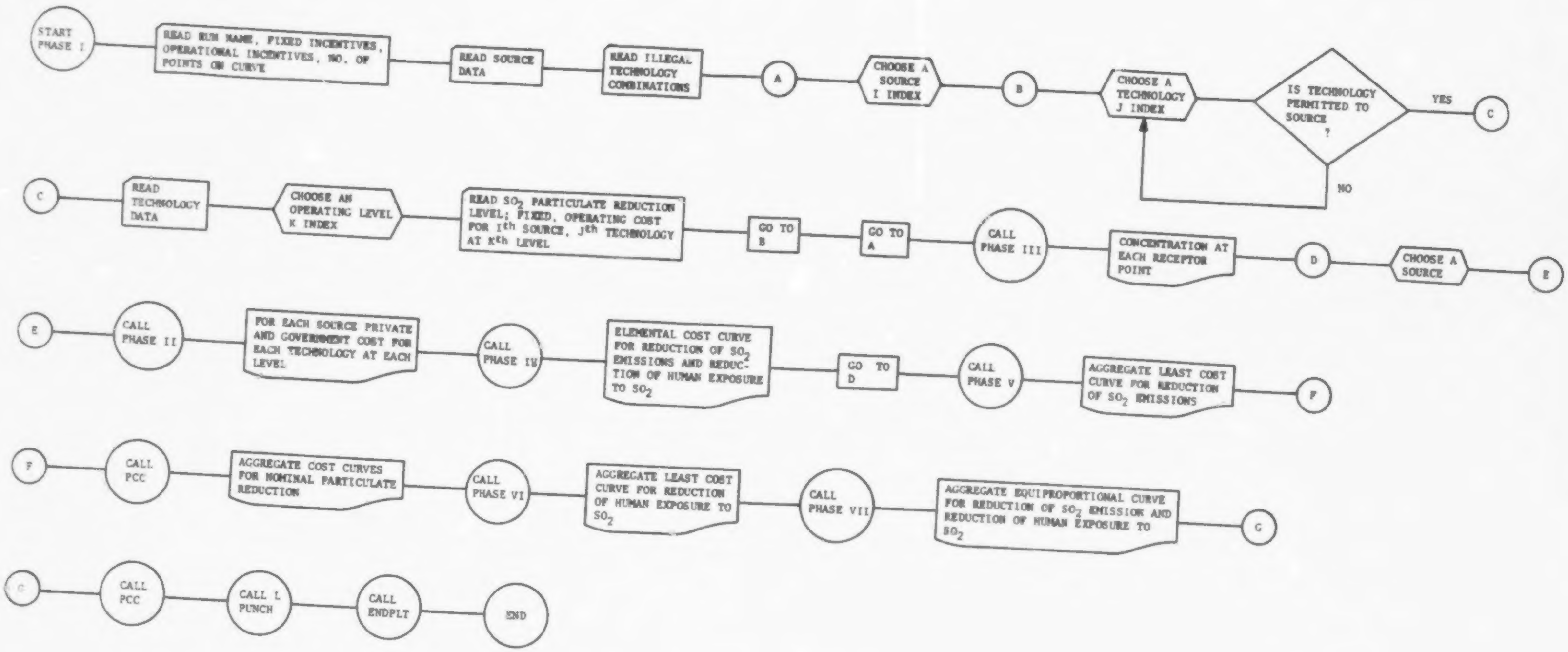
```
      SUBROUTINE CHART (ARRAY,NPOINT,NLINE)
      COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
      DIMENSION ARRAY(12,2,7)
      XMAX1 = 0.
      YMAX1 = 0.
C *** SET THE MAX X,Y VALUES
      DO 25 I=1,NLINE
      XMAX1= MAX1F(ARRAY(NPOINT,1,I),XMAX1)
25    YMAX1= MAX1F(ARRAY(NPOINT,2,I),YMAX1)
C *** SET XMAX TO 25,50,75, OR 100 PER CENT
      XMAX = 25.
      IF(XMAX1 .LE. 25.)GO TO 50
      XMAX = 50.
      IF(XMAX1 .LE. 50.)GO TO 50
      XMAX = 75.
      IF(XMAX1 .LE. 75.)GO TO 50
      XMAX = 100.
50    CONTINUE
C *** SET YMAX TO A CONVENIENT VALUE.
      IF(YMAX1 .GT. 0.1)GO TO 63
C *** ERROR COMMENT FOR BAD DATA
      CALL SYMBOL(2.,5.,.35,5HERROR,0.,5)
      RETURN
63    N=5
61    IF(YMAX1 .GE. 10.**N)GO TO 62
      N=N-1
      GO TO 61
62    Y=YMAX1/(5.*10.**(N-1))
      YMAX = INTF(Y+1.)*(5.*10.**(N-1))
C *** DRAW THE BOX
      CALL BOX(XMAX/5.,YMAX/5.,N)
C *** DRAW THE LINES WITHIN THE BOX
      DO 100 I=1,NLINE
100   CALL LINE(XMAX,YMAX,JSYMBL(I),ARRAY(1,1,I),NPOINT)
      RETURN
      END
```

```
      SUBROUTINE INIT
      COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
      DIMENSION BUF(400)
      DATA (NPG = 0)
C *** INITIALIZE IF THIS IS THE FIRST PAGE.
      IF(NPG.EQ.0) CALL PLOTS(BUF,400,40,10)
      CALL PLOT(8.5,9.,-3)
      CALL PLOT(0.,  9.3,  2)
      NPG = NPG+1
      RETURN
      END
      SUBROUTINE LINE(XMAX,YMAX,ISYMBL,ARRAX,NOPTS)
      COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
      DIMENSION ARRAX(12,2)
      CALL PLOT(X0,Y0;3)
      CALL PLOT(X0,Y0,2)
      DO 50 I=1,NOPTS
      X= 5.*ARRAX(I,1)/XMAX + X0
      Y= 5.*ARRAX(I,2)/YMAX + Y0
50    CALL SYMBOL(X,Y,.12,ISYMBL ,0.,-2)
      RETURN
      END
```

```
      SUBROUTINE PRCENTS(DATA,NLINE)
      COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
      DIMENSION DATA(7)
      CALL SYMBOL(4,25-6.0 *CHAR, 6,05, .10, 16, 0., -1)
      CALL SYMBOL(4,25-17,*CHAR, 6.,SIZE,
     *  34HSYMBOL         PARTICULATE REDUCTION, 0.,34)
      DO 50 I=1,NLINE
      CALL SYMBOL(4,25-14,5*CHAR, 6,05-I*SPACE, .10, JSYMBL(I), 0., -1)
50    CALL NUMBER(4,25+3.*CHAR,6,-I*SPACE,SIZE,DATA(I), 0.,4HF5.1)
      RETURN
      END
```

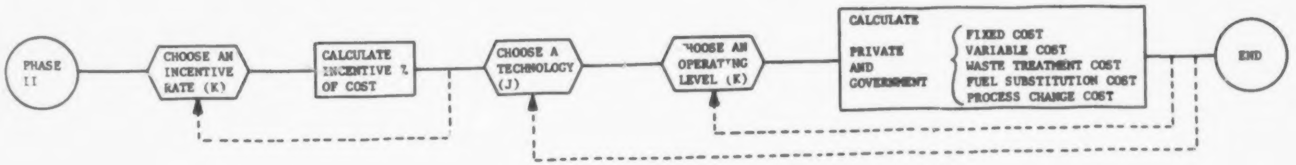
```
      SUBROUTINE ENDPLT
      COMMON /PLOTR/ X0,Y0,SIZE,CHAR,SPACE,JSYMBL(7)
      CALL INIT
      CALL SYMBOL(2.,6.,1.,3HEND,0.,3)
      CALL PLOT(8,5,0.,-3)
      CALL STOPPLOT
      RETURN
      END
```

MODEL CITY II
MAIN PROGRAM (PHASE I) FLOW CHART

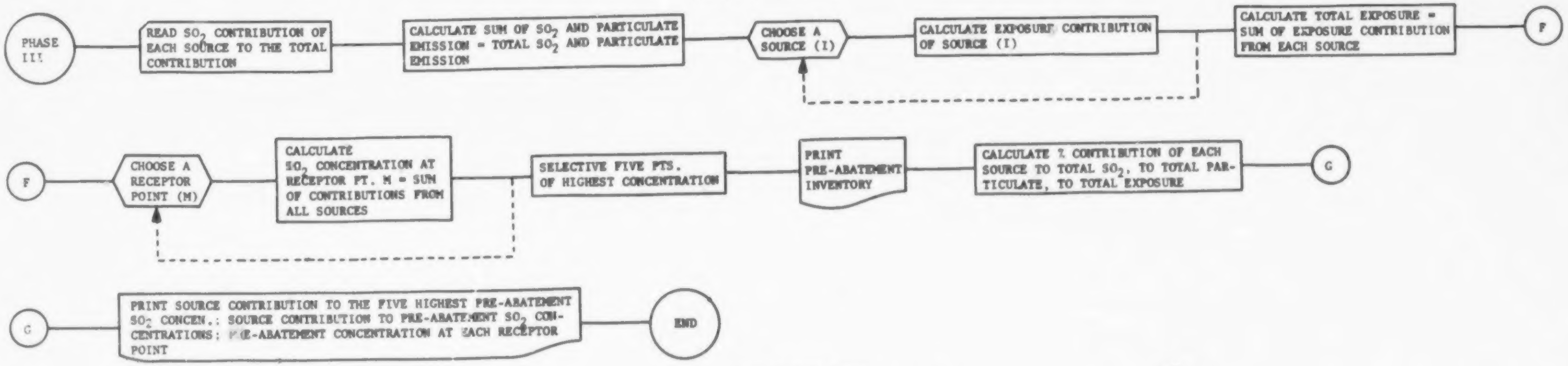

START PHASE I
READ RUN NAME, FIXED INCENTIVES, OPERATIONAL INCENTIVES, NO. OF POINTS ON CURVE
READ SOURCE DATA
READ ILLEGAL TECHNOLOGY COMBINATIONS
A
CHOOSE A SOURCE I INDEX
B
CHOOSE A TECHNOLOGY J INDEX
IS TECHNOLOGY PERMITTED TO SOURCE ?
YES
NO
C
C
READ TECHNOLOGY DATA
CHOOSE AN OPERATING LEVEL K INDEX
READ SO2 PARTICULATE REDUCTION LEVEL; FIXED, OPERATING COST FOR Ith SOURCE, Jth TECHNOLOGY AT Kth LEVEL
GO TO B
GO TO A
CALL PHASE III
CONCENTRATION AT EACH RECEPTOR POINT
D
CHOOSE A SOURCE
E
E
CALL PHASE II
FOR EACH SOURCE PRIVATE AND GOVERNMENT COST FOR EACH TECHNOLOGY AT EACH LEVEL
CALL PHASE IV
ELEMENTAL COST CURVE FOR REDUCTION OF SO2 EMISSIONS AND REDUCTION OF HUMAN EXPOSURE TO SO2
GO TO D
CALL PHASE V
AGGREGATE LEAST COST CURVE FOR REDUCTION OF SO2 EMISSIONS
F
F
CALL PCC
AGGREGATE COST CURVES FOR NOMINAL PARTICULATE REDUCTION
CALL PHASE VI
AGGREGATE LEAST COST CURVE FOR REDUCTION OF HUMAN EXPOSURE TO SO2
CALL PHASE VII
AGGREGATE EQUIPROPORTIONAL CURVE FOR REDUCTION OF SO2 EMISSION AND REDUCTION OF HUMAN EXPOSURE TO SO2
G
G
CALL PCC
CALL L PUNCH
CALL ENDPLT
END

MODEL CITY II
SUBPROGRAM FLOW CHARTS

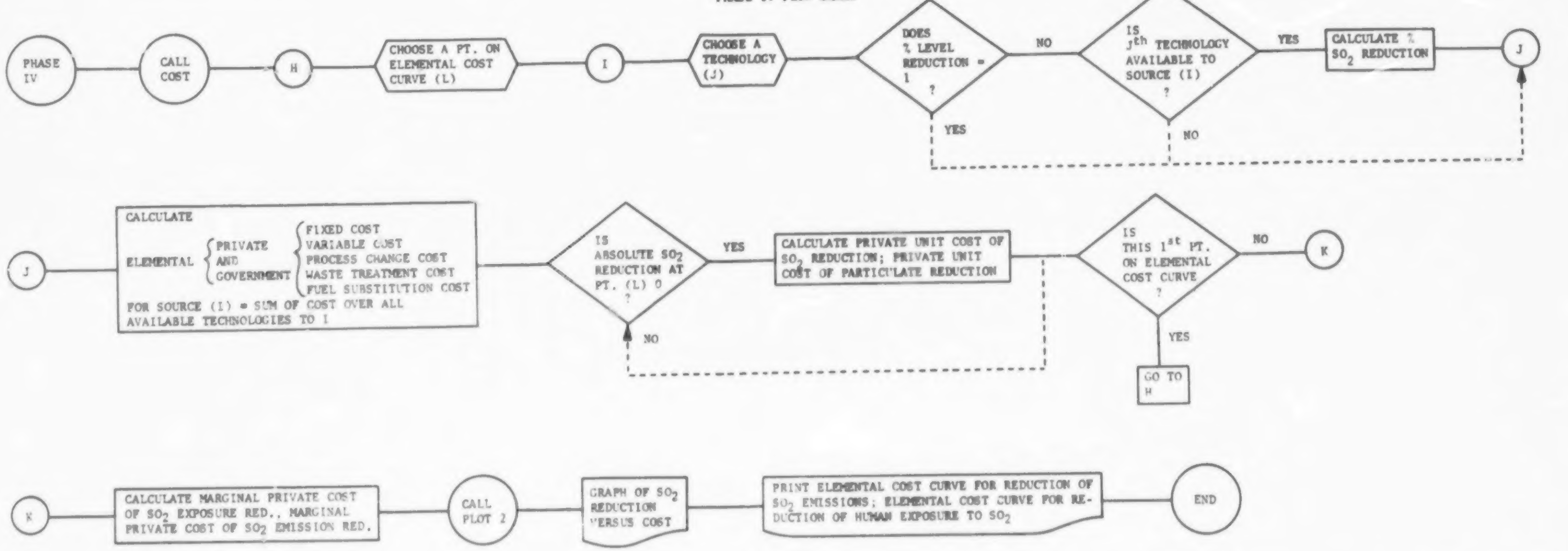
PHASE II FLOW CHART


PHASE II
CHOOSE AN INCENTIVE RATE (K)
CALCULATE INCENTIVE % OF COST
CHOOSE A TECHNOLOGY (J)
CHOOSE AN OPERATING LEVEL (K)
CALCULATE
PRIVATE AND GOVERNMENT
FIXED COST
VARIABLE COST
WASTE TREATMENT COST
FUEL SUBSTITUTION COST
PROCESS CHANGE COST
END

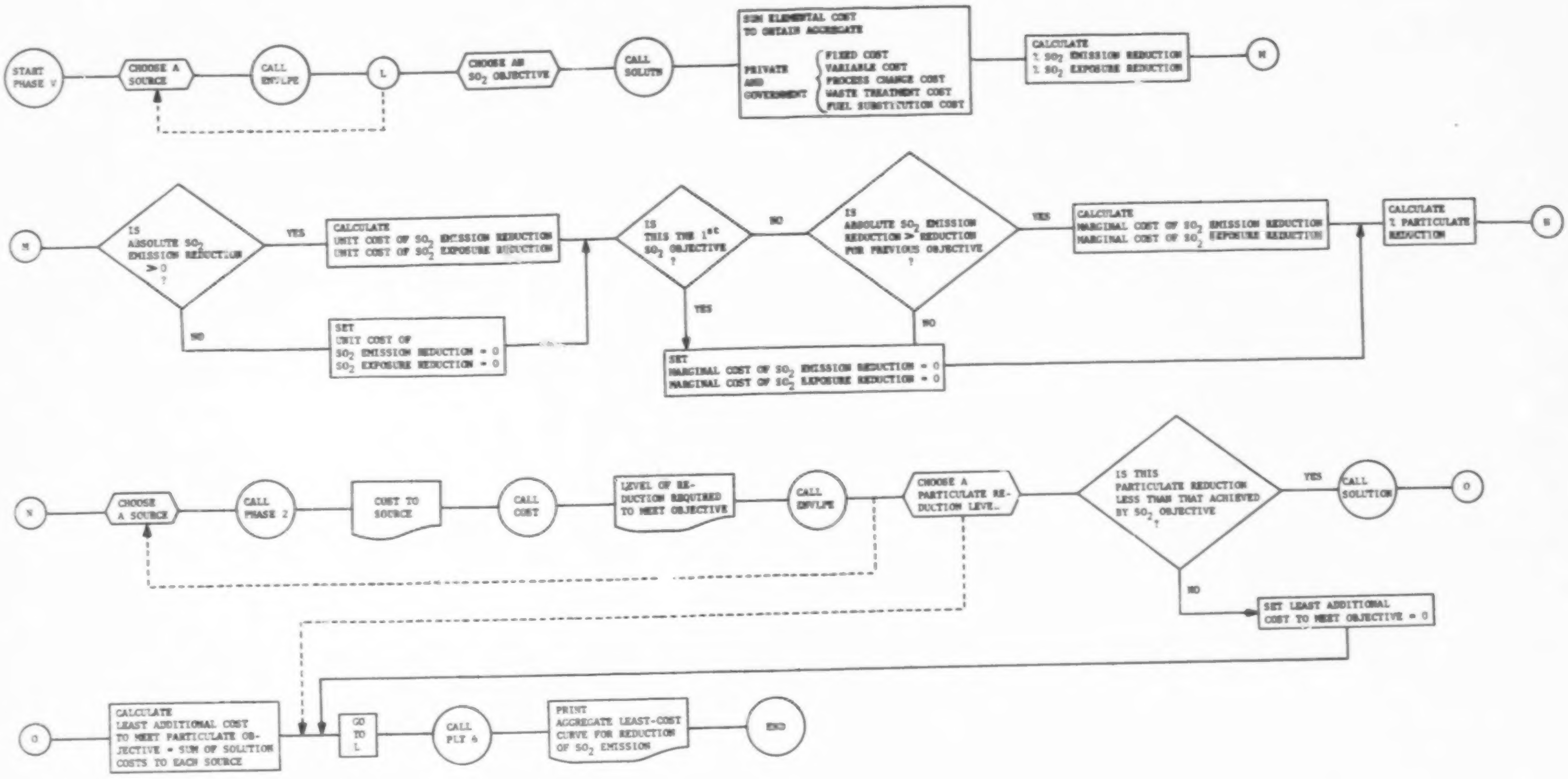
PHASE III FLOW CHART


PHASE III
READ SO_2 CONTRIBUTION OF EACH SOURCE TO THE TOTAL CONTRIBUTION
CALCULATE SUM OF SO_2 AND PARTICULATE EMISSION = TOTAL SO_2 AND PARTICULATE EMISSION
CHOOSE A SOURCE (I)
CALCULATE EXPOSURE CONTRIBUTION OF SOURCE (I)
CALCULATE TOTAL EXPOSURE = SUM OF EXPOSURE CONTRIBUTION FROM EACH SOURCE
F
F
CHOOSE A RECEPTOR POINT (M)
CALCULATE SO_2 CONCENTRATION AT RECEPTOR PT. M = SUM OF CONTRIBUTIONS FROM ALL SOURCES
SELECTIVE FIVE PTS. OF HIGHEST CONCENTRATION
PRINT PRE-ABATEMENT INVENTORY
CALCULATE % CONTRIBUTION OF EACH SOURCE TO TOTAL SO_2, TO TOTAL PARTICULATE, TO TOTAL EXPOSURE
G
G
PRINT SOURCE CONTRIBUTION TO THE FIVE HIGHEST PRE-ABATEMENT SO_2 CONCEN.; SOURCE CONTRIBUTION TO PRE-ABATEMENT SO_2 CONCENTRATIONS; PRE-ABATEMENT CONCENTRATION AT EACH RECEPTOR POINT
END

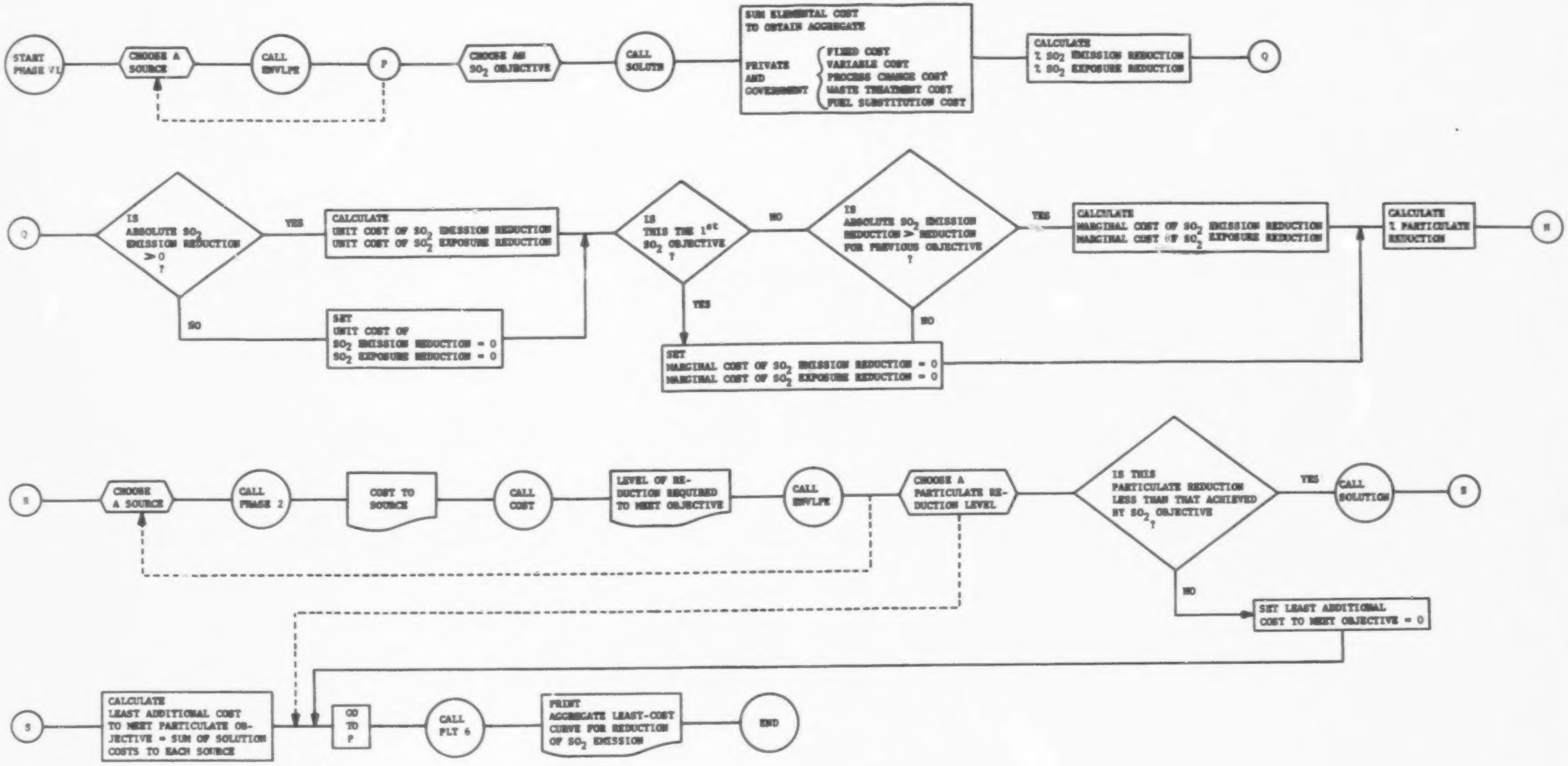
PHASE IV FLOW CHART


PHASE IV
CALL COST
H
CHOOSE A PT. ON ELEMENTAL COST CURVE (L)
I
CHOOSE A TECHNOLOGY (J)
DOES % LEVEL REDUCTION = 1 ?
NO
YES
IS J^{th} TECHNOLOGY AVAILABLE TO SOURCE (I) ?
YES
NO
CALCULATE % SO_2 REDUCTION
J
J
CALCULATE
ELEMENTAL
PRIVATE AND GOVERNMENT
FIXED COST
VARIABLE COST
PROCESS CHANGE COST
WASTE TREATMENT COST
FUEL SUBSTITUTION COST
FOR SOURCE (I) = SUM OF COST OVER ALL AVAILABLE TECHNOLOGIES TO I
IS ABSOLUTE SO_2 REDUCTION AT PT. (L) 0 ?
YES
NO
CALCULATE PRIVATE UNIT COST OF SO_2 REDUCTION; PRIVATE UNIT COST OF PARTICULATE REDUCTION
IS THIS 1^{st} PT. ON ELEMENTAL COST CURVE ?
NO
YES
GO TO H
K
K
CALCULATE MARGINAL PRIVATE COST OF SO_2 EXPOSURE RED., MARGINAL PRIVATE COST OF SO_2 EMISSION RED.
CALL PLOT 2
GRAPH OF SO_2 REDUCTION VERSUS COST
PRINT ELEMENTAL COST CURVE FOR REDUCTION OF SO_2 EMISSIONS; ELEMENTAL COST CURVE FOR REDUCTION OF HUMAN EXPOSURE TO SO_2
END

MODEL CITY II
SUBPROGRAM FLOW CHARTS
PHASE V FLOW CHART

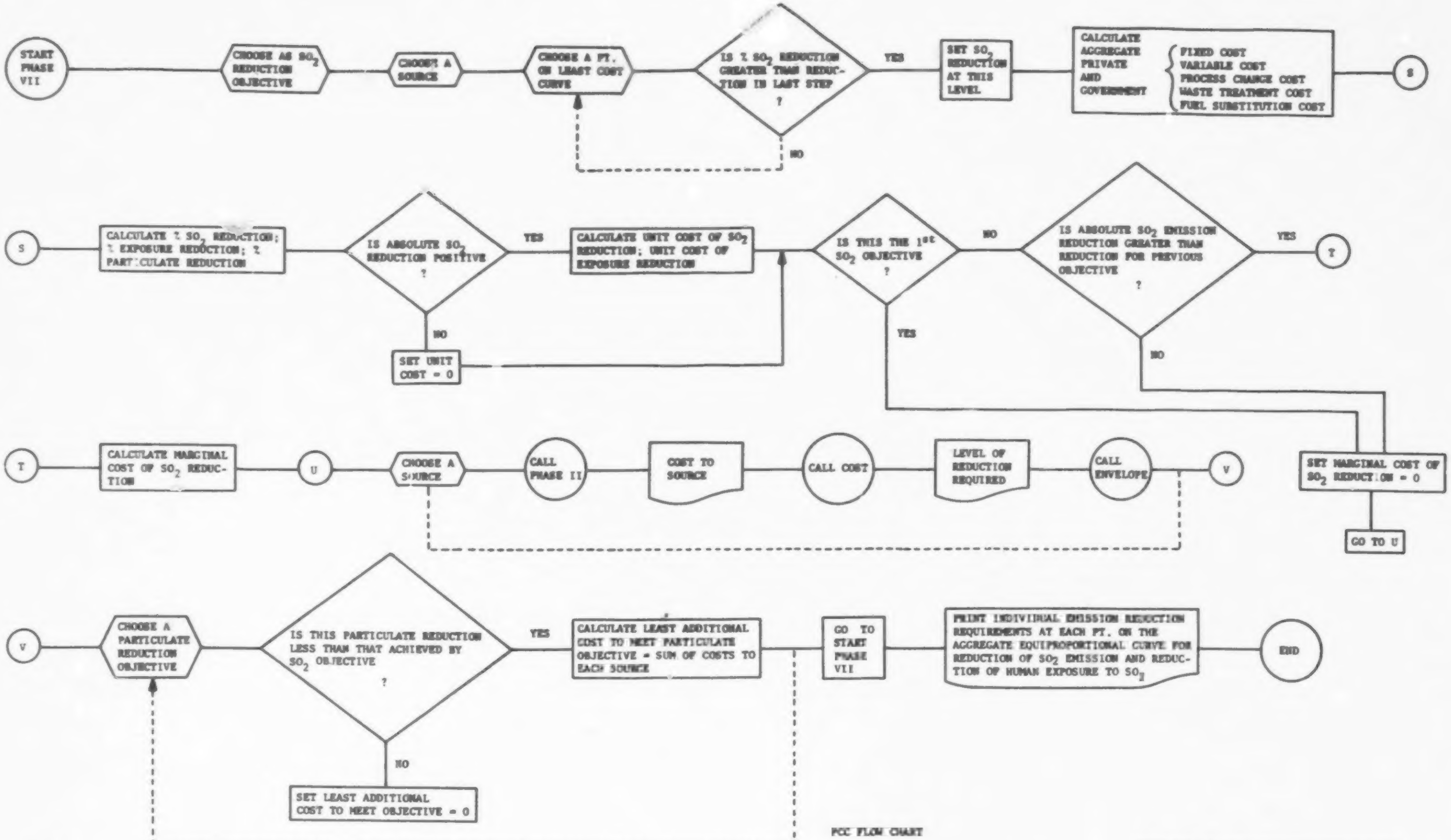

START PHASE V
CHOOSE A SOURCE
CALL ENVLPE
L
CHOOSE AN SO2 OBJECTIVE
CALL SOLUTN
SUM ELEMENTAL COST TO OBTAIN AGGREGATE
PRIVATE AND GOVERNMENT
FIXED COST
VARIABLE COST
PROCESS CHANGE COST
WASTE TREATMENT COST
FUEL SUBSTITUTION COST
CALCULATE % SO2 EMISSION REDUCTION % SO2 EXPOSURE REDUCTION
M
M
IS ABSOLUTE SO2 EMISSION REDUCTION > 0 ?
YES
NO
CALCULATE UNIT COST OF SO2 EMISSION REDUCTION UNIT COST OF SO2 EXPOSURE REDUCTION
SET UNIT COST OF SO2 EMISSION REDUCTION = 0 SO2 EXPOSURE REDUCTION = 0
IS THIS THE 1st SO2 OBJECTIVE ?
NO
YES
IS ABSOLUTE SO2 EMISSION REDUCTION > REDUCTION FOR PREVIOUS OBJECTIVE ?
YES
NO
CALCULATE MARGINAL COST OF SO2 EMISSION REDUCTION MARGINAL COST OF SO2 EXPOSURE REDUCTION
SET MARGINAL COST OF SO2 EMISSION REDUCTION = 0 MARGINAL COST OF SO2 EXPOSURE REDUCTION = 0
CALCULATE % PARTICULATE REDUCTION
N
N
CHOOSE A SOURCE
CALL PHASE 2
COST TO SOURCE
CALL COST
LEVEL OF REDUCTION REQUIRED TO MEET OBJECTIVE
CALL ENVLPE
CHOOSE A PARTICULATE REDUCTION LEVEL
IS THIS PARTICULATE REDUCTION LESS THAN THAT ACHIEVED BY SO2 OBJECTIVE ?
YES
NO
CALL SOLUTION
O
SET LEAST ADDITIONAL COST TO MEET OBJECTIVE = 0
O
CALCULATE LEAST ADDITIONAL COST TO MEET PARTICULATE OBJECTIVE = SUM OF SOLUTION COSTS TO EACH SOURCE
GO TO L
CALL PLT 6
PRINT AGGREGATE LEAST-COST CURVE FOR REDUCTION OF SO2 EMISSION
END

PHASE VI FLOW CHART


START PHASE VI
CHOOSE A SOURCE
CALL ENVLPE
P
CHOOSE AN SO2 OBJECTIVE
CALL SOLUTN
SUM ELEMENTAL COST TO OBTAIN AGGREGATE
PRIVATE AND GOVERNMENT
FIXED COST
VARIABLE COST
PROCESS CHANGE COST
WASTE TREATMENT COST
FUEL SUBSTITUTION COST
CALCULATE % SO2 EMISSION REDUCTION % SO2 EXPOSURE REDUCTION
Q
Q
IS ABSOLUTE SO2 EMISSION REDUCTION > 0 ?
YES
NO
CALCULATE UNIT COST OF SO2 EMISSION REDUCTION UNIT COST OF SO2 EXPOSURE REDUCTION
SET UNIT COST OF SO2 EMISSION REDUCTION = 0 SO2 EXPOSURE REDUCTION = 0
IS THIS THE 1st SO2 OBJECTIVE ?
NO
YES
IS ABSOLUTE SO2 EMISSION REDUCTION > REDUCTION FOR PREVIOUS OBJECTIVE ?
YES
NO
SET MARGINAL COST OF SO2 EMISSION REDUCTION = 0 MARGINAL COST OF SO2 EXPOSURE REDUCTION = 0
CALCULATE MARGINAL COST OF SO2 EMISSION REDUCTION MARGINAL COST OF SO2 EXPOSURE REDUCTION
CALCULATE % PARTICULATE REDUCTION
R
R
CHOOSE A SOURCE
CALL PHASE 2
COST TO SOURCE
CALL COST
LEVEL OF REDUCTION REQUIRED TO MEET OBJECTIVE
CALL ENVLPE
CHOOSE A PARTICULATE REDUCTION LEVEL
IS THIS PARTICULATE REDUCTION LESS THAN THAT ACHIEVED BY SO2 OBJECTIVE ?
YES
NO
CALL SOLUTION
S
SET LEAST ADDITIONAL COST TO MEET OBJECTIVE = 0
S
CALCULATE LEAST ADDITIONAL COST TO MEET PARTICULATE OBJECTIVE = SUM OF SOLUTION COSTS TO EACH SOURCE
GO TO P
CALL PLT 6
PRINT AGGREGATE LEAST-COST CURVE FOR REDUCTION OF SO2 EMISSION
END

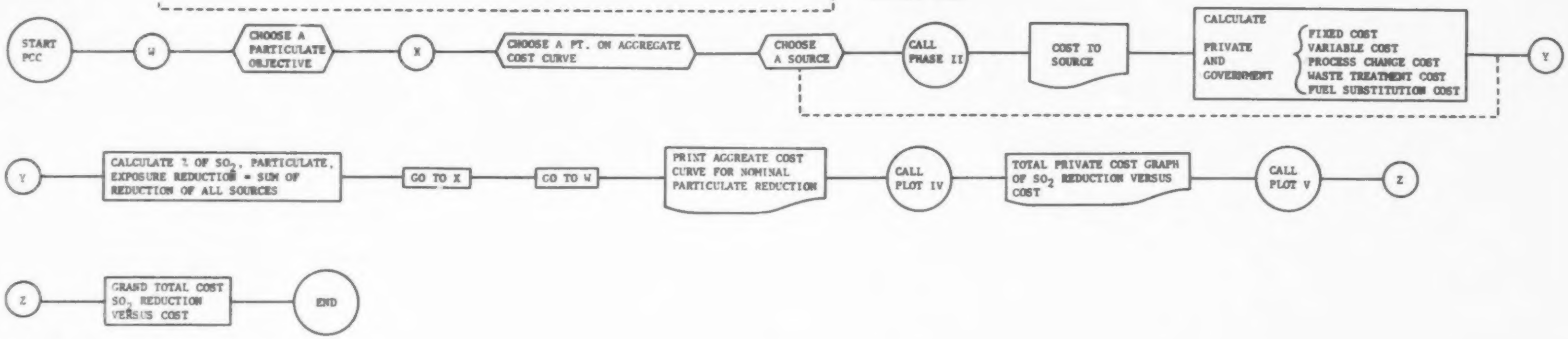
MODEL CITY II
SUBPROGRAM FLOW CHARTS, CONT'D.

PHASE VII FLOW CHART



START PHASE VII
CHOOSE AN SO_2 REDUCTION OBJECTIVE
CHOOSE A SOURCE
CHOOSE A PT. ON LEAST COST CURVE
IS % SO_2 REDUCTION GREATER THAN REDUCTION IS LAST STEP ?
YES
NO
SET SO_2 REDUCTION AT THIS LEVEL
CALCULATE AGGREGATE PRIVATE AND GOVERNMENT
FIXED COST
VARIABLE COST
PROCESS CHANGE COST
WASTE TREATMENT COST
FUEL SUBSTITUTION COST
S
S
CALCULATE % SO_2 REDUCTION; % EXPOSURE REDUCTION; % PARTICULATE REDUCTION
IS ABSOLUTE SO_2 REDUCTION POSITIVE ?
YES
NO
SET UNIT COST = 0
CALCULATE UNIT COST OF SO_2 REDUCTION; UNIT COST OF EXPOSURE REDUCTION
IS THIS THE 1st SO_2 OBJECTIVE ?
NO
YES
IS ABSOLUTE SO_2 EMISSION REDUCTION GREATER THAN REDUCTION FOR PREVIOUS OBJECTIVE ?
YES
NO
T
SET MARGINAL COST OF SO_2 REDUCTION = 0
GO TO U
T
CALCULATE MARGINAL COST OF SO_2 REDUCTION
U
CHOOSE A SOURCE
CALL PHASE II
COST TO SOURCE
CALL COST
LEVEL OF REDUCTION REQUIRED
CALL ENVELOPE
V
V
CHOOSE A PARTICULATE REDUCTION OBJECTIVE
IS THIS PARTICULATE REDUCTION LESS THAN THAT ACHIEVED BY SO_2 OBJECTIVE ?
YES
NO
SET LEAST ADDITIONAL COST TO MEET OBJECTIVE = 0
CALCULATE LEAST ADDITIONAL COST TO MEET PARTICULATE OBJECTIVE = SUM OF COSTS TO EACH SOURCE
GO TO START PHASE VII
PRINT INDIVIDUAL EMISSION REDUCTION REQUIREMENTS AT EACH PT. ON THE AGGREGATE EQUIPROPORTIONAL CURVE FOR REDUCTION OF SO_2 EMISSION AND REDUCTION OF HUMAN EXPOSURE TO SO_2
END

PCC FLOW CHART



START PCC
W
CHOOSE A PARTICULATE OBJECTIVE
X
CHOOSE A PT. ON AGGREGATE COST CURVE
CHOOSE A SOURCE
CALL PHASE II
COST TO SOURCE
CALCULATE
PRIVATE AND GOVERNMENT
FIXED COST
VARIABLE COST
PROCESS CHANGE COST
WASTE TREATMENT COST
FUEL SUBSTITUTION COST
Y
Y
CALCULATE % OF SO_2, PARTICULATE, EXPOSURE REDUCTION = SUM OF REDUCTION OF ALL SOURCES
GO TO X
GO TO W
PRINT AGGREGATE COST CURVE FOR NOMINAL PARTICULATE REDUCTION
CALL PLOT IV
TOTAL PRIVATE COST GRAPH OF SO_2 REDUCTION VERSUS COST
CALL PLOT V
Z
Z
GRAND TOTAL COST SO_2 REDUCTION VERSUS COST
END

180

APPENDIX C

METHODS OF ESTIMATING ANNUAL COSTS OF EMISSION CONTROL ALTERNATIVES

APPENDIX C

METHODS OF ESTIMATING ANNUAL COSTS OF EMISSION CONTROL ALTERNATIVES

The nature of costs associated with emission control alternatives available to stationary combustion sources is shown in Exhibit C-1.

EXHIBIT C-1

NATURE OF COSTS ASSOCIATED WITH EMISSION CONTROL ALTERNATIVES

Control Technology Alternative	Nature of Costs
Fuel substitution	Fuel
Fuel switching	Fuel Boiler conversion
Mechanical control (including sulfur recovery system and afterburners)	Purchase and installation Operating and maintenance
SO_2 stack gas cleaning processes	Purchase and installation Operating and maintenance

The methodologies used in computing these costs follow.

INPUTS AND CALCULATIONS REQUIRED TO DETERMINE THE COST AND EFFECTIVENESS OF FUEL SUBSTITUTION OR SWITCHING

INPUTS - COSTS

Cost per million Btu of present fuel
Cost per million Btu of alternative fuel
Fuel consumption per hour in million Btu
Annual hours of operation [1]
Annualized boiler conversion costs [2]

INPUTS - EMISSIONS

Emissions per hour using present fuel
Emissions per hour using alternative fuel
Annual hours of operation [1]

CALCULATIONS

		Cost per million Btu of alternative fuel
(Step 1)	-	Cost per million Btu of present fuel
		Unit cost differential per million Btu
(Step 2)	x	Fuel consumption per hour in million Btu
		Additional fuel cost per hour
(Step 3)	x	Annual hours of operation [1]
		Additional annual fuel cost
(Step 4)[2]	+	Annualized boiler conversion costs
		Additional annual cost
		Emissions per hour using present fuel
(Step 5)	-	Emissions per hour using alternative fuel
		Emissions reduced per hour
(Step 6)	x	Annual hours of operation [1]
		Annual Emissions Reduced
		Additional annual fuel cost
		or
		Additional annual cost [2]
(Step 7)	÷	Annual emissions reduced
		COST PER POUND OF EMISSIONS REDUCED

[1] Hours per year X percent utilization.
[2] Fuel switching only.

COST ESTIMATING METHOD FOR AIR POLLUTION CONTROL EQUIPMENT

Step 1. Describe the emission source, including type and characteristics of the process, the characteristics and consumption rate of fuel for a stationary combustion source of particulates, and the annual hours of operation.

Step 2. Select the applicable type or types of control equipment.

Step 3. Express the required efficiencies for the selected control equipment and specify the required pressure drops. Take any existing control into account.

Capital Costs

Step 4. Determine the capitalized purchase cost:

A depreciation period of 15 years was used for this equipment. An amount equal to depreciation was allowed for interest, certain taxes, and other capital-related costs. The straight line method of depreciation is assumed, since this method has the simplicity of a uniform annual write-off. Thus, the estimated annual capital cost of control equipment is:

$$\text{Capitalized Purchase Cost} = 2 \times \frac{\text{Purchase Cost}}{\text{15 years}}$$

$$= \frac{\text{Purchase Cost}}{7.5}$$

This formula was also used in computing the capitalized purchasing cost of afterburners and sulfur recovery system.

In the Model City I, Model City II, Washington, D. C., and New York-New Jersey studies interest, taxes, and other charges to capital were not included. In those studies the formula for capitalized purchase cost was

$$\text{Capitalized Purchase Cost} = \frac{\text{Purchase Cost}}{15}$$

Step 5. (a) Multiply the cost found in the preceding step by the low, mean, and high installation percentage. (b) Add the result to the capitalized purchase cost to yield the low, mean, and high annual capital cost estimates.

Operating and Maintenance Costs

Step 6. Compute the low, mean, and high cost in the subject area of electricity, maintenance, and make-up liquor (for wet scrubbers).

Step 7. Compute low, mean, and high operating and maintenance costs A, from the appropriate formula.

Mechanical collector:

$$A = S \left[\frac{PHK}{8506E} + M\right]$$

where

S = the design capacity of the mechanical collector expressed in actual cubic feet per minute (acfm)

8506 = a constant to convert the result to dollars per acfm

E = the fan efficiency, which is assumed to be 70 percent, expressed as a decimal, 0.7

P = the pressure drop in inches of water

H = annual hours of operation

K = the local cost for electricity in dollars per kilowatt-hour

K_1 = low electricity cost

K_m = mean electricity cost

K_h = high electricity cost

M = the local cost of maintenance in dollars per acfm

M_1 = low maintenance cost

M_m = mean maintenance cost

M_h = high maintenance cost

Wet scrubber:

$$A = S \left[\frac{PHK}{8506E} + M + WHL\right]$$

where

L = the cost of liquor in dollars per gallon

L_1 = low liquor cost

L_m = mean liquor cost

L_h = high liquor cost

W = make-up liquor rate in gallons per acfm

185

See mechanical collector formula for definitions of S, P, H, K, E, M, and the constant 8506.

Electrostatic precipitator:

$$A = S\left[JHK + M\right]$$

where

S, H, K, and M are as for above formulas

J = killowatt hours of electricity per thousand acfm, depending on efficiency of equipment

J_l = low efficiency equipment = 0.19/1000 acfm

J_h = high efficiency equipment = 0.34/1000 acfm

Fabric filters:

$$A = S\left[\frac{PHK}{8506E} + M\right]$$

See mechanical collector formula for definitions of S, P, H, K, M, E and the constant 8506.

Afterburners:

The operating cost was assumed to be the cost of the natural gas required for heat to support the combustion in the afterburner:

Unit cost differential per million Btu = Cost per million Btu of natural gas - Cost per million Btu of present fuel

A = Unit cost differential per million Btu x
Fuel consumption per hour in million Btu
Additional fuel cost per hour

x Annual hours of operation
Additional annual fuel cost

Sulfur Recovery System:

Operating costs of the sulfur recovery unit were assumed to be negligible.

Assumptions Applying to Operating Cost Elements

(1) Power costs included in annual operating expense are for the electricity used by all systems directly associated with the control equipment. Electrical power requirements are computed on a constant usage per 1000 acfm per inch pressure drop.

(2) In the case of equipment using water, it is assumed that the water is circulated in a closed loop system, and that the usage is the make-up water rate.

(3) The costs for electricity and water are computed on the marginal rate classes for each size user. This assumes that any additional consumption will be priced at the lowest rate, highest volume class available. A price range covers the different rate structures where more than one utility exists in a given area. In the case of a power plant, it is assumed that electricity is used and is priced at production cost.

(4) Increased disposal cost for collected effluents is not included in operating costs, but neither is disposal cost decreased by the sale of recovered by-products or by the recovery of heat from the exhaust gases. Because this is a generalized model, no attempt is made to account for these expenses or savings.

Assumptions Applying to Maintenance Cost Elements

(1) The preventive, or scheduled, maintenance program that is carried out maintains the equipment close to its original operating efficiency. Though maintenance costs generally increase as equipment ages, a constant maintenance cost is assumed here.

(2) Any unscheduled maintenance (due to random failure) is undertaken as required, with negligible loss of operating time.

Total Estimated Mean Annual Cost

Step 8. Add the mean annual capital cost to the mean operating and maintenance cost to yield the total estimated mean annual cost. To determine the total estimated mean annual cost for a combination of equipment types, the cost obtained in this step is added to the total estimated mean annual costs, computed similarly, of all other emissions control equipment to be used for the emission.

Step 9. Compute the low cost variance (V_l) and the high cost variance (V_h) of an equipment combination using the following formulae.

$$V_h = \sqrt{(C_{hi} - C_{mi})^2 + (A_{hi} - A_{mi})^2 + \ldots + (C_{hn} - C_{mn})^2 + (A_{hn} - A_{mn})^2}$$

$$V_l = \sqrt{(C_{mi} - C_{li})^2 + (A_{mi} - A_{li})^2 + \ldots + (C_{mn} - C_{ln})^2 + (A_{mn} - A_{ln})^2}$$

where

C_{mi} = the mean annual capital cost of equipment i (i = 1, 2, 3, . . ., n)

C_{li} = the low annual capital cost of the same equipment

C_{hi} = the high annual capital cost of the same equipment

A_{mi} = the mean annual operating and maintenance cost of equipment i (i = 1, 2, 3, . . ., m)

A_{li} = the low annual operating and maintenance cost of the same equipment

A_{hi} = the high annual operating and maintenance cost of the same equipment

The above formulae are taken from the usual definition of the standard error of a linear combination of statistically independent variables.

Step 10. The high cost variance (V_h) is added to the total estimated mean annual cost to yield the high cost limit.

The low cost variance (V_l) is subtracted from the total estimated mean annual cost to yield the low cost limit.

These limits are not absolute. In some unusual cases costs might exceed the high cost limit or be lower than the low cost limit.

SO_2 Stack Gas Cleaning Processes

Estimated costs of purchase, installation, and operation of SO_2 stack gas cleaning processes are based entirely on available technical literature, supplemented by interviews with one of the authors.

Three SO_2 stack gas cleaning processes are currently undergoing tests. None have thus far been placed in other than pilot plant operation in this country. For these studies, it has been assumed that one or more of these processes would, in fact, be available as an SO_2 emission control alternative.

The cost of these processes consists of two components - capital and operations. The capital costs are based on the estimated construction costs appearing in the literature, adjusted for plant size (rated generating capacity). As with other capital costs, a depreciation life of 15 years has been used for the SO_2 stack gas cleaning process capital costs. No provision has been made for other costs associated with these processes, such as insurance, property taxes, or interest.

Operating expenses are also based on those appearing in the literature and have been adjusted to reflect actual plant size. They have also been adjusted, where appropriate, to reflect a total based on coal prices in the study area. The three processes that currently exist each have about the same effect on SO_2 (about 90 percent removal). The cost of each of these processes, as determined in accordance with the definitions given above, are different, not only in total, but also in terms of capital and operating costs. In order to reflect these differences, the cost actually used as average was the middle cost process, alkalized alumina.

189

EXAMPLES OF CALCULATIONS

EXAMPLE OF CALCULATIONS TO DETERMINE THE COST AND EFFECTIVENESS OF FUEL SWITCHING

Exhibit C-2 shows the calculations to determine the cost and emission reduction effectiveness of a fuel switch from coal to oil in an industrial boiler.

EXAMPLE OF CALCULATIONS TO DETERMINE THE COST OF AIR POLLUTION CONTROL EQUIPMENT

In this example the cost estimating methodology for air pollution control equipment is applied to a hypothetical source of particulate emissions, a power plant.

The example chosen here is a small power plant producing approximately 50 megawatts a year. This power plant is an arbitrarily chosen example only. It is realistic, but its characteristics are not representative of every emission source or of all power plants.

In Exhibit C-2 the step-by-step procedure for determining control equipment cost described in this appendix is applied to the source to calculate the total estimated cost of the equipment combination specified.

Exhibit C-2

COST EFFECTIVENESS OF FUEL SWITCHING OF COAL WITH FUEL OIL IN AN INDUSTRIAL BOILER

Boiler Description

Boiler horsepower	1700
Fuel consumption	75,000,000 BTU per hour at maximum utilization
Furnace type (present)	Pulverized wet bottom without reinjection

Present Fuel

Coal
- 3.2% sulfur by weight
- 371.0 pounds of sulfur dioxide emitted per hour at maximum utilization
- 9% ash content by weight
- 362.7 pounds of particulate emitted per hour at maximum utilization
- 32¢ per million BTU

Switching Fuels

No. 6 fuel oil
- 2.5% sulfur by weight
- 193.7 pounds of sulfur dioxide emitted per hour at maximum utilization
- 3.9 pounds of particulate emitted per hour at maximum utilization
- 49¢ per million BTU
- $4,000 annualized boiler conversion costs

Natural gas using interruptible service

Natural gas
- A trace of sulfur dioxide emitted per hour at maximum utilization
- 1.4 pounds of particulate emitted per hour at maximum utilization
- 28¢ per million BTU
- $4,000 annualized boiler conversion costs

No. 2 fuel oil
- 0.25% sulfur by weight
- 21.8 pounds of sulfur dioxide emitted per hour at maximum utilization
- 4.4 pounds of particulate emitted per hour at maximum utilization
- 72¢ per million BTU

Exhibit C-2 (Cont'd)

Cost Effectiveness of Fuel Switching of Coal with Fuel Oil in an Industrial Boiler

I. Switching to low sulfur no. 6 fuel oil

Cost Differential	
Low sulfur no. 6 fuel oil cost per million BTU	$ 0.49
(Step 1) High sulfur coal cost per million BTU	-0.32
Unit cost differential per million BTU	0.17
(Step 2) Fuel consumption per hour (million BTU)	X 75
Additional fuel cost per hour	$ 12.75
(Step 3) Annual hours of operation (365 days a year, 24 hours a day, 60% utilization)	X 5,265
Additional annual fuel cost	$67,128.75
(Step 4) Annualized boiler conversion costs	+4,000.00
Additional annual cost	$71,128.75

Emissions Reduced	Sulfur Dioxide	Particulate
Emissions per hour using present fuel	377.0 pounds	362.7 pounds
(Step 5) Emissions per hour using low sulfur no. 6 fuel oil	-193.7 pounds	3.9 pounds
Pounds of emissions reduced per hour	183.3	358.8
(Step 6) Annual hours of operation	X 5,265	X 5,265
Annual emissions reduced	965,074.5 pounds	1,889,082.0 pounds
Cost per Pound of Emissions Reduced		
Additional annual cost (from Step 4)	$71,128.75	$71,128.75
(Step 7) Annual emissions reduced (from Step 6)	÷965,074.5	÷1,889,082.0
Cost per pound of emissions reduced	$ 0.074	$ 0.038

192

Exhibit C-2 (Cont'd)

Cost Effectiveness of Fuel Switching of Coal with Fuel Oil in an Industrial Boiler

II. Switching to natural gas using interruptible service

Assumption: Natural gas is used alone to generate 90 percent of the heat consumed annually. The remaining 10 percent is generated by no. 2 fuel oil.

Cost Differential		
Natural gas cost per million BTU	$ 0.28	$ 0.72
No. 2 fuel oil cost per million BTU		
(Step 1) High sulfur coal cost per million BTU	-0.32	-0.32
Unit cost differential per million BTU		
natural gas	-0.04	
no. 2 fuel oil		0.40
(Step 2) Fuel consumption per hour (million BTU)	X 75	X 75
Additional (decreased) fuel cost per hour	($ 3.00)	$ 30.00
(Step 3) Annual hours of operation (365 days a year, 24 hours a day, 60% utilization)	X 5,265	X 5,265
Additional (decreased) annual fuel cost (100% usage)	($15,795.00)	$157,950.00
Percent of annual fuel consumption		
natural gas	0.90	
no. 2 fuel oil		0.10
Additional (decreased) annual cost		
natural gas	($14,215.50)	
no. 2 fuel oil		15,795.00
Additional annual fuel cost		1,579.50
(Step 4) Annualized boiler conversion costs		+4,000.00
Additional annual cost		$ 5,579.50

Exhibit C-2 (Cont'd)

Cost Effectiveness of Fuel Switching of Coal with Fuel Oil in an Industrial Boiler

	Sulfur Dioxide	Particulate
Emissions Reduced - natural gas		
Emissions per hour using present fuel	377.0 pounds	362.7 pounds
(Step 5) Emissions per hour using natural gas	-Trace	1.4 pounds
Pounds of emissions reduced per hour	377.0	361.3
(Step 6) Annual hours of operation	X 5,265	X 5,265
Annual emissions reduced (100% usage)	1,984,905	1,902,244.5
Percent of natural gas consumption	0.90	0.90
Annual emissions reduced	1,786,415 pounds	1,712,020 pounds
Emissions Reduced - no. 2 fuel oil		
Emissions per hour using present fuel	377.0 pounds	362.7 pounds
(Step 5) Emissions per hour using natural gas	-21.8 pounds	-4.4 pounds
Pounds of emissions reduced per hour	355.2	358.3
(Step 6) Annual hours of operation	X 5,265	X 5,265
Annual emissions reduced (100% usage)	1,870,128	1,886,450
Percent of no. 2 fuel oil consumption	0.10	0.10
Annual emissions reduced	187,013 pounds	188,645 pounds
Cost per Pound of Emissions		
Additional annual cost (from Step 4)	$5,579.50	$5,579.50
(Step 7) Annual emissions reduced (from Steps 6)	÷1,973,428	÷1,900,665
	$ 0.00283	$0.00293

EXHIBIT C-3

COST OF AIR POLLUTION CONTROL EQUIPMENT: EXAMPLE CALCULATIONS [a]

Step 1. Description of the emission source.

The characteristics of the example power plant follow:

Furnace type — Cyclone

Present fuels	Coal	Natural Gas
Percent ash by weight	10.0%	trace
Annual fuel usage	51,000 tons	1533.3 X 10^6 cubic feet

Present control — None

Present annual particulate emissions — 521.4 tons (short) per year [b]

Exhaust gas volume, S — 200,000 acfm

Annual hours of operation, H — 8,760 (24 hours a day, 365 days a year)

Step 2. Selected control equipment.

The control equipment proposed is a high efficiency mechanical collector followed by an electrostatic precipitator. The mechanical collector removes the larger particles (10 microns or larger) before the gas stream reaches the electrostatic precipitator.

Step 3. Required efficiencies and pressure drops of selected equipment.

	Equipment Efficiency	Pressure Drop, P, in Inches of Water	Collection Efficiency
Mechanical collector	high	8	50
Electrostatic precipitator	high	1/2	98

---

[a] Example calculations and all costs were taken from Reference 4.

[b] Coal of 10 percent ash content yields 20 pounds of ash per ton of coal burned in a cyclone furnace. Natural gas yields 15 pounds of ash per 10^6 cubic feet.

195

The mechanical collector, though of high efficiency, is presumed only 50 percent efficient when applied to a power plant because of the relatively small size of most of the emitted particles.

The capital, operating, and maintenance costs and the sum, are computed separately (Steps 4 through 8) for the two control equipments.

Steps 4, 5a, 5b. Capital cost of high efficiency mechanical collector.

(Step 4) Estimated Capitalized Purchase Cost = \$6,200

(Step 5a) Installation Cost

		Low	Mean	High
(Step 5a)	Percentage of capitalized purchase cost	40%	50%	100%
	Installation Cost	\$2,480	\$3,100	\$6,200
(Step 5b)	Estimated Annual Capital Cost = Capitalized purchase + installation costs	\$8,680 $=C_{l_1}$	\$9,300 $=C_{m_1}$	\$12,400 $=C_{h_1}$

Steps 6, 7. Operating and maintenance cost of high efficiency mechanical collector.

$$A = S\left[167.9 \times 10^{-6}\ PHK + M\right]$$

(Step 6) where K_l = \$0.0030/kwh
K_m = 0.0050/kwh
K_h = 0.0080/kwh

M_l = \$0.0050/acfm (actual cubic feet per minute)
M_m = 0.0150/acfm
M_h = 0.0250/acfm

(from step 1)
S = 200,000 acfm
H = 8,760 hours

(from step 3)
P = 8 inches

(Step 7)

Low Operating and Maintenance Cost.

$$A_{l_1} = 200{,}000 \left[(167.9 \times 10^{-6}) \quad (8) \quad (8760) \quad (0.0030) + (0.0050)\right]$$
$$= 8{,}058$$
Use $A_{l_1} =$ \$8,100

Mean Operating and Maintenance Cost

$$A_{m_1} = 200{,}000 \left[(167.9 \times 10^{-6}) \quad (8) \quad (8760) \quad (0.0050) + (0.0150)\right]$$
$$= 14{,}764$$
Use $A_{m_1} =$ \$14,800

High Operating and Maintenance Cost

$$A_{h_1} = 200{,}000 \left[(167.9 \times 10^{-6}) \quad (8) \quad (8760) \quad (0.0080) + (0.0250)\right]$$
$$= 23{,}826$$
Use $A_{h_1} =$ \$23,800

Step 8. Estimated mean annual cost of high efficiency mechanical collector.

Mean capital cost	\$ 9,300
Mean operating and maintenance cost	14,800
Total Estimated Mean Annual Cost	\$24,100

Steps 4, 5a, 5b. Capital cost of high efficiency electrostatic precipitator.

(Step 4) Estimated Capitalized Purchase Cost = \$14,250

(Step 5a) Installation Cost

	Low	Mean	High
Percentage of capitalized purchase cost	35%	70%	100%
Installation Cost	\$4,988	\$9,975	\$14,250

(Step 5b) Estimated Annual Capital Cost = Capitalized purchase + installation costs

	Low	Mean	High
Estimated Annual Capital Cost = Capitalized purchase + installation costs	\$19,238 $=C_{l2}$	\$24,225 $=C_{m2}$	\$28,500 $=C_{h2}$

Steps 6, 7. Operating and maintenance cost of high efficiency electrostatic precipitator.

$$A = S\left[JHK + M\right]$$

(Step 6) where J = 0.34 kwh/1000 acfm

K_l = \$0.0030/kwh
K_m = 0.0050/kwh
K_h = 0.0080/kwh

M_l = \$0.010/acfm
M_m = 0.020/acfm
M_h = 0.030/acfm

(from step 1)

S = 200,000 acfm
H = 8,760 hours

(Step 7)

Low Operating and Maintenance Cost:

$$A_{l2} = 200{,}000 \left[(0.00034)\ (8760)\ (0.0030) + (0.010)\right]$$
$$= 3{,}787$$
Use A_{l2} = \$3,800

Mean Operating and Maintenance Cost

$$A_{m2} = 200{,}000 \left[(0.00034)\ (8760)\ (0.0050) + (0.020)\right]$$
$$= 6{,}978$$
Use A_{m2} = \$7,000

High Operating and Maintenance Cost

$$A_{h2} = 200{,}000 \left[(0.00034)\ (8760)\ (0.0080) + (0.030)\right]$$
$$= 10{,}765$$
Use A_{h2} = \$10,800

Step 8. Estimated mean annual cost of high efficiency electrostatic precipitator and of combination of equipment.

Mean capital cost of electrostatic precipitator	\$24,225
Mean operating and maintenance cost of electrostatic precipitator	7,000
Total Estimated Mean Annual Cost of Electrostatic Precipitator	\$31,225
Total estimated mean annual cost of mechanical collector	24,100
Total Estimated Mean Annual Cost of Combination	\$55,325

Step 9. High and low cost variances.

High variance

$$V_h = \sqrt{(C_{h_1} - C_{m_1})^2 + (A_{h_1} - A_{m_1})^2 + (C_{h2} - C_{m2})^2 + (A_{h2} - A_{m2})^2}$$

$$= \sqrt{(12{,}400 - 9{,}300)^2 + (23{,}800 - 14{,}800)^2 + (28{,}500 - 24{,}225)^2 + (10{,}800 - 7{,}000)^2}$$

$$= \sqrt{125{,}125{,}625}$$

$$= 11{,}186$$

Use V_h = $11,200

Low variance

$$V_l = \sqrt{(C_{m_1} - C_l)^2 + (A_{m_1} - A_l)^2 + (C_{m2} - C_{l2})^2 + (A_{m2} - A_{l2})^2}$$

$$= \sqrt{(9{,}300 - 8{,}680)^2 + (14{,}800 - 8{,}100)^2 + (24{,}225 - 19{,}238)^2 + (7{,}000 - 3{,}800)^2}$$

$$= \sqrt{80{,}384{,}569}$$

$$= 8{,}965$$

Use V_l = $9,000

Step 10. High and low cost estimates.

High Cost Estimate = Total estimated mean annual cost + V_h

= $55,325 + $11,200

= $66,525

or $66,500

Low Cost Estimate = Total estimated mean annual cost - V_l

= $55,325 -$9,000

= $46,325

or $46,300

199

APPENDIX D

CONCEN, AG, SORT, SORTCON, AND INTCODE

PROGRAM LISTINGS AND FLOW CHARTS

APPENDIX D

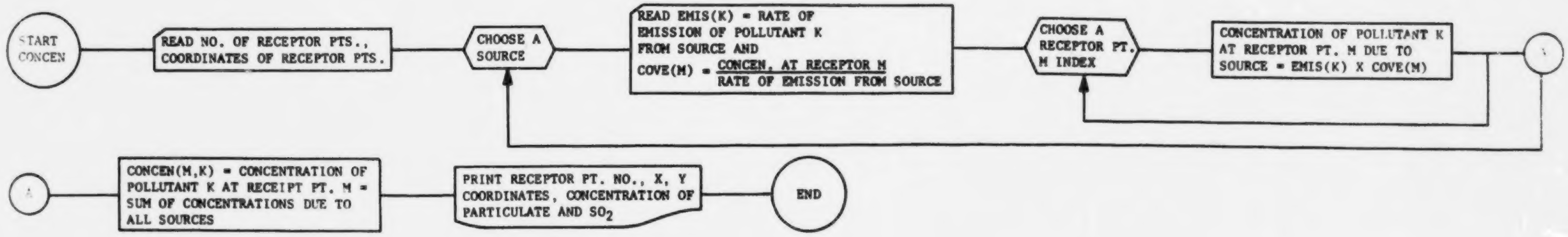
CONCEN, AG, SORT, SORTCON, AND INTCODE PROGRAM LISTINGS AND FLOW CHARTS

CONCEN

The CONCEN program uses the output of the MET program to compute the concentration of the pollutants at each receptor point due to each individual source. These concentrations are computed by multiplying the rate of emission of the pollutant from the source (read in as data to the program) times the concentration of the pollutant at the receptor point per unit emission from the source (output of the MET program.) The CONCEN program in addition computes the pre-abatement concentration of SO_x and SP at each receptor point due to all sources by summing the concentrations from all the sources. Following are a flow diagram of the program and the program listing.

201

CONCEN PROGRAM FLOW CHART


START CONCEN
READ NO. OF RECEPTOR PTS., COORDINATES OF RECEPTOR PTS.
CHOOSE A SOURCE
READ EMIS(K) = RATE OF EMISSION OF POLLUTANT K FROM SOURCE AND
COVE(M) = CONCEN, AT RECEPTOR M / RATE OF EMISSION FROM SOURCE
CHOOSE A RECEPTOR PT. M INDEX
CONCENTRATION OF POLLUTANT K AT RECEPTOR PT. M DUE TO SOURCE = EMIS(K) X COVE(M)
A
A
CONCEN(M,K) = CONCENTRATION OF POLLUTANT K AT RECEIPT PT. M = SUM OF CONCENTRATIONS DUE TO ALL SOURCES
PRINT RECEPTOR PT. NO., X, Y COORDINATES, CONCENTRATION OF PARTICULATE AND SO2
END

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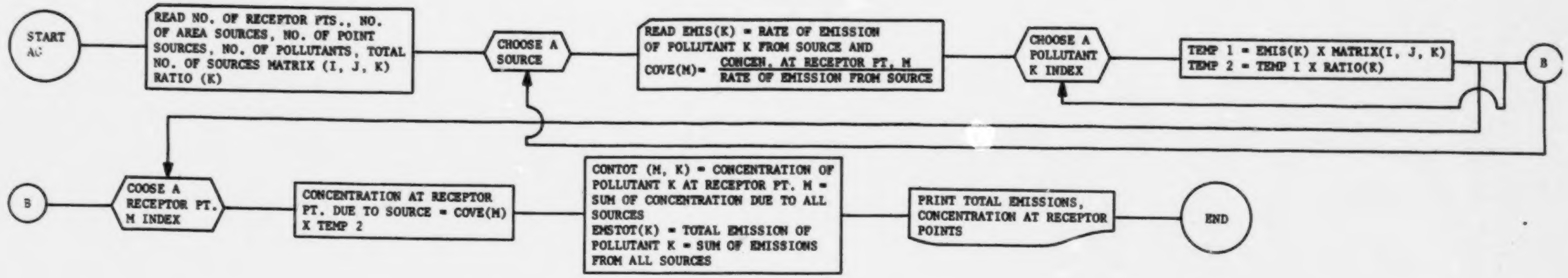
```
      PROGRAM CONCENTR
      DIMENSION XRECEP(60), YRECEP(60), MATRIX(8,13,5), VECTOR(8,5),
     1    RATIO(5), CONCEN(60,5), EMIS(5), COVE(60)
      REAL MATRIX
C    M7 = NO. OF RECEPTOR POINTS
      READ (60,1) M7
    1  FORMAT (I5)
      READ (60,25) (  XRECEP(M),YRECEP(M),M=1,M7)
   25 FORMAT (10F8.2)
      DO 24 K=1,2
      DO 24 I=1,7
   24 READ (60,23) (MATRIX(I,J,K),J=1,12)
   23 FORMAT (1X, 12F5.0)
      RATIO(1)=2.7083
      RATIO(2)=0.001
      DO 22 M=1,M7
      DO 22 K=1,2
   22 CONCEN(M,K)=0.0
      DO 37 LS=1,849
   30 READ (10,506)NUM,SHOR,SVER,HS,G,W,MAT,NCOUNT,(EMIS(K),K=1,2),
     1      (COVE(M),M=1,M7)
      IF(EOFCKF(10).EQ.1) 31,32
C     IF (EOF,10           ) 31,32
  506 FORMAT (I8, 2F6.1, 2F6.2, F5.0, I2, I3,6(/1X,10E13.5))
   32 DO 37 K=1,2
      TEMP=RATIO(K)*EMIS(K)
      DO 37 M=1,M7
   37 CONCEN(M,K)=CONCEN(M,K)+TEMP*COVE(M)
      PRINT 33, NUM
   33 FORMAT (1X,I8)
   31 WRITE (61,40)
   40 FORMAT (1H1///7X,                          43
     1HRECEPTOR                CONCENTRATIONS                       /7X, 56
     2 HPOINT        PART        SO2                                /7X, 57
     3 HX     Y    (UG/CU-M)    (PPM)                                /)
      DO 42 M=1,M7
   42 WRITE (61,41) M, XRECEP(M),YRECEP(M),(CONCEN(M,K),K=1,2)
   41 FORMAT(4X,I3,4X,2F6.1,2E10.3/)
      READ (10,506)NUM,SHOR,SVER,HS,G,W,MAT,NCOUNT,(EMIS(K),K=1,2),
     1      (COVE(M),M=1,M7)
      IF(EOFCKF(10).EQ.1) 998,999
  998 CONTINUE
  999 CONTINUE
      STOP
      END
```

AG

The AG program, like the CONCEN program, uses the output of the MET program to compute the concentration of the pollutants at each receptor point due to each source and totals the individual contributions to the concentration to obtain pre-abatement concentrations due to all sources. The AG program further permits totaling of the pollution contribution of small sources by user type such as distillate oil burners, diesel trains, open burning, etc. The program listing and flow charts for this program are shown on the following pages.

204

AG PROGRAM FLOW CHART


START AG
READ NO. OF RECEPTOR PTS., NO. OF AREA SOURCES, NO. OF POINT SOURCES, NO. OF POLLUTANTS, TOTAL NO. OF SOURCES MATRIX (I, J, K) RATIO (K)
CHOOSE A SOURCE
READ EMIS(K) = RATE OF EMISSION OF POLLUTANT K FROM SOURCE AND COVE(M)= CONCEN. AT RECEPTOR PT. M / RATE OF EMISSION FROM SOURCE
CHOOSE A POLLUTANT K INDEX
TEMP 1 = EMIS(K) X MATRIX(I, J, K) TEMP 2 = TEMP I X RATIO(K)
B
B
COOSE A RECEPTOR PT. M INDEX
CONCENTRATION AT RECEPTOR PT. DUE TO SOURCE = COVE(M) X TEMP 2
CONTOT (M, K) = CONCENTRATION OF POLLUTANT K AT RECEPTOR PT. M = SUM OF CONCENTRATION DUE TO ALL SOURCES EMSTOT(K) = TOTAL EMISSION OF POLLUTANT K = SUM OF EMISSIONS FROM ALL SOURCES
PRINT TOTAL EMISSIONS, CONCENTRATION AT RECEPTOR POINTS
END

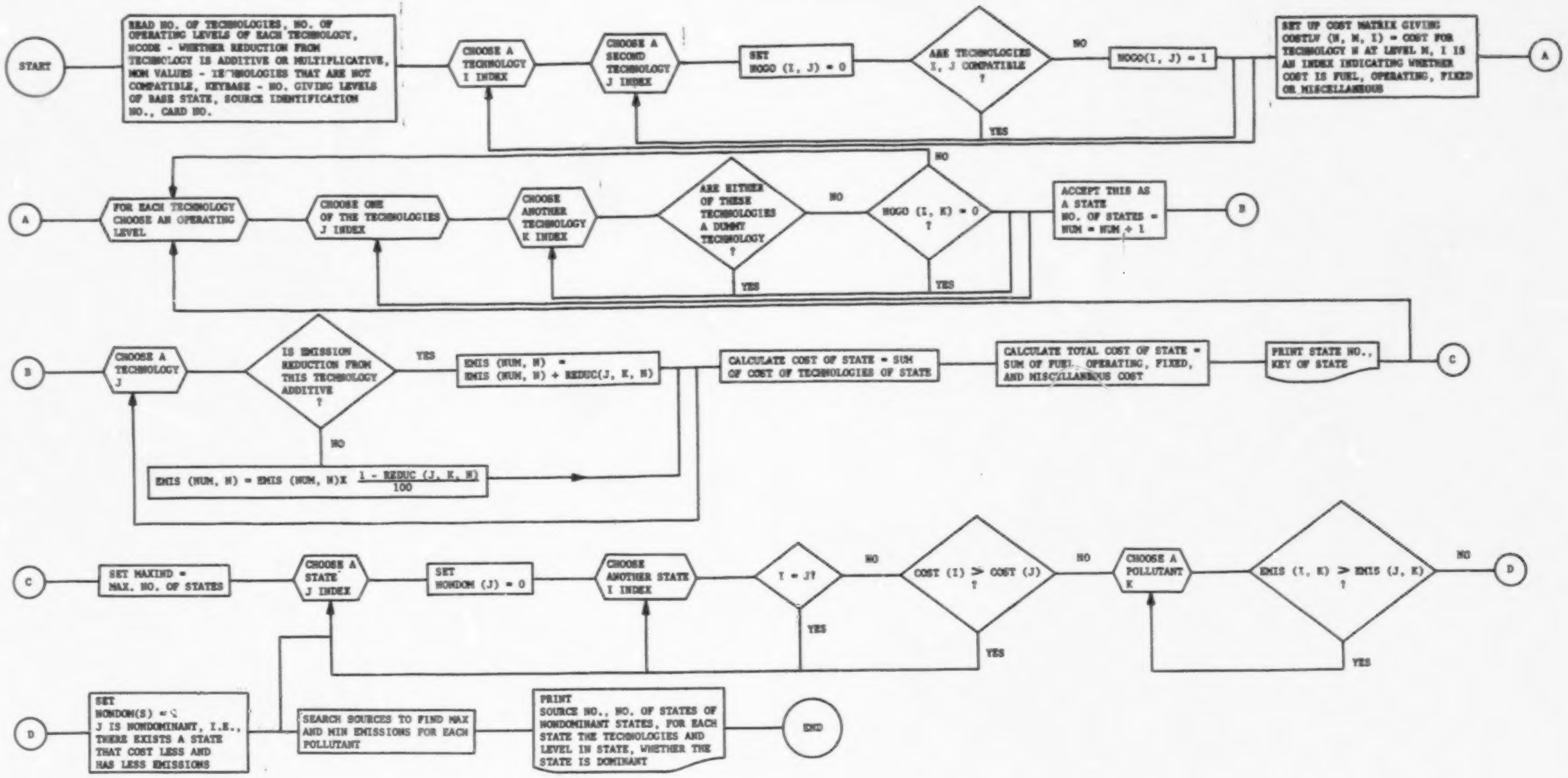
```
      PROGRAM AG
      DIMENSION EMSTOT(5),         CONTOT(5,60),EMIS(5),CONCEN(5,60),
     1     COVE(60),MATRIX(8,13,5),RATIO(5)
      REAL MATRIX
      REWIND 10
      REWIND 11
      RATIO(1)=2.7083
      RATIO(2)=0.001
      DO 24 K=1,2
      DO 24 I=1,7
   24 READ (60,23) (MATRIX(I,J,K),J=1,12)
   23 FORMAT (1X, 12F5.0)
      READ(60,74) NRECEP,NOARSC,NUMPOL,NOUSE,KEY1,KEY2,NPTSRC
   74 FORMAT(20I4)
      DO 199 LINE=1,NOUSE
      LL=0
      GO TO (71,72,71,72,71,72,71,72,71,72,71,72 ),LINE
   72 LL=LL+1
   71 LL=LL+1
      DO 88 K=1,NUMPOL
      EMSTOT(K)=0.0
      DO 88 M=1,NRECEP
   88 CONTOT(K,M)=0.0
      DO 100 LF=1,NOARSC
      GO TO (91,92        ),LL
   91 READ(11,506         )NUM,A,B,C,D,E,MAT,J,(EMIS(K),K=1,NUMPOL),
     1     (COVE(M),M=1,NRECEP)
  506 FORMAT (I8, 2F6.1, 2F6.2, F5.0, I2, I3,6(/1X,10E13.5))
      GO TO 95
   92 READ(10,506         )NUM,A,B,C,D,E,MAT,J,(EMIS(K),K=1,NUMPOL),
     1     (COVE(M),M=1,NRECEP)
   95 DO 100 K=1,NUMPOL
      TEMP1=EMIS(K)*MATRIX(MAT,LINE,K) /100.0
      EMSTOT(K)=EMSTOT(K)+TEMP1
       TEMP2=TEMP1*RATIO(K)
      DO 100 M=1,NRECEP
  100 CONTOT(K,M)=CONTOT(K,M)+COVE(M)*TEMP2
      IF (LINE-NOUSE) 111,110,110
  111 REWIND 11
      REWIND 10
  110 WRITE(25,112        )LINE,(EMSTOT(K),(CONTOT(K,M),M=1,NRECEP),K=1
     1    NUMPOL)
  112 FORMAT(I5,/(8E13.5/))
  199 CONTINUE
      ENDFILE 25
      IF (KEY1) 128,125,121
  121 DO 124 KF=1,NPTSRC
      READ(10,506         )NUM,A,B,C,D,E,MAT,J,(EMIS(K),K=1,NUMPOL),
     1     (COVE(M),M=1,NRECEP)
      IF (EOFCKF(10).EQ.1) 122,124
  124 WRITE(25,112        )NUM,(EMIS(K),K=1,NUMPOL),(COVE(M),M=1,NRECEP
  122 ENDFILE 25
      REWIND 25
  125 IF (KEY2) 128,128,127
  127 DO 129 K=1,NUMPOL
      DO 129 M=1,NRECEP
  129 CONCEN(K,M)=0.0
  130 READ (25,1121        )LINE
      IF (EOFCKF(25).EQ.1) 131,132
  132 READ (25,1122)                (EMSTOT(K),(CONTOT(K,M),M=1,NRECEP),K=1,
     1    NUMPOL)
```

```
1121 FORMAT(I5)
1122 FORMAT(8E13.5/)
     DO 133 K=1,NUMPOL
     DO 133 M=1,NRECEP
 133 CONCEN(K,M)=CONCEN(K,M)*CONTOT(K,M)
     GO TO 130
 131 READ (25,1121) NUM
     IF (EOFCKF(25).EQ.1) 134,135
 135 READ (25,1122)             (EMIS(K),K=1,NUMPOL),(COVE(M),M=1,NRECEP)
     DO 136 K=1,NUMPOL
     TEMP1=EMIS(K)*RATIO(K)
     DO 136 M=1,NRECEP
 136 CONCEN(K,M)=CONCEN(K,M)+TEMP1*COVE(M)
     GO TO 131
 134 DO 137 M=1,NRECEP
 137 WRITE (61,138) M,(CONCEN(K,M),K=1,NUMPOL)
 138 FORMAT (I5,2E15.4)
 128 STOP
     END
```

SORT

The SORT program is used to enumerate all possible emission control states (combinations of emission control technologies) for each source. This program is run once for each source. Input to this program is the source's control device data-technologies available, operating levels for each technology, technologies that are not compatible, and control cost. The program then tests to find all permissible combinations of controls - control states. The emission rate and cost of each state is then computed. The program also tests to see if the state is dominant, that is, whether there are any other states which both cost less and have less emissions. A simplified flow chart for this program and the FORTRAN program listing follow.

SORT PROGRAM FLOW CHART

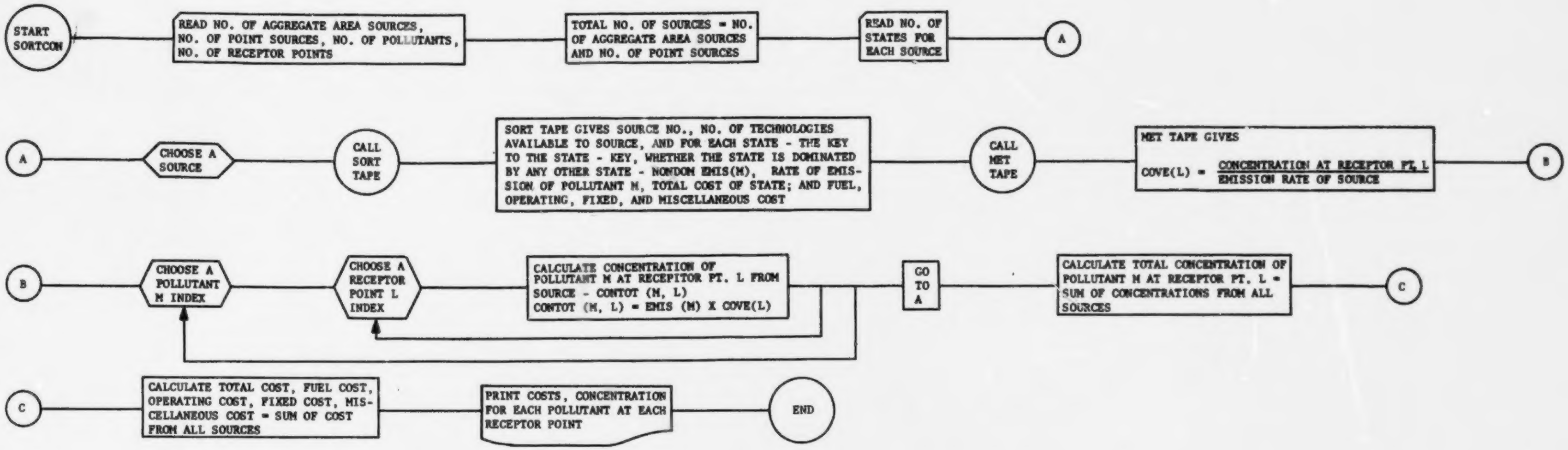

START
READ NO. OF TECHNOLOGIES, NO. OF OPERATING LEVELS OF EACH TECHNOLOGY, NCODE - WHETHER REDUCTION FROM TECHNOLOGY IS ADDITIVE OR MULTIPLICATIVE, NOM VALUES - TECHNOLOGIES THAT ARE NOT COMPATIBLE, KEYBASE - NO. GIVING LEVELS OF BASE STATE, SOURCE IDENTIFICATION NO., CARD NO.
CHOOSE A TECHNOLOGY I INDEX
CHOOSE A SECOND TECHNOLOGY J INDEX
SET NOGO (I, J) = 0
ARE TECHNOLOGIES I, J COMPATIBLE ?
NO
NOGO(I, J) = 1
YES
SET UP COST MATRIX GIVING COSTLV (N, M, I) = COST FOR TECHNOLOGY N AT LEVEL M, I IS AN INDEX INDICATING WHETHER COST IS FUEL, OPERATING, FIXED OR MISCELLANEOUS
A
A
FOR EACH TECHNOLOGY CHOOSE AN OPERATING LEVEL
CHOOSE ONE OF THE TECHNOLOGIES J INDEX
CHOOSE ANOTHER TECHNOLOGY K INDEX
ARE EITHER OF THESE TECHNOLOGIES A DUMMY TECHNOLOGY ?
NO
YES
NOGO (I, K) = 0 ?
NO
YES
ACCEPT THIS AS A STATE NO. OF STATES = NUM = NUM + 1
B
B
CHOOSE A TECHNOLOGY J
IS EMISSION REDUCTION FROM THIS TECHNOLOGY ADDITIVE ?
YES
EMIS (NUM, N) = EMIS (NUM, N) + REDUC(J, K, N)
NO
EMIS (NUM, N) = EMIS (NUM, N)X 1 - REDUC (J, K, N) / 100
CALCULATE COST OF STATE = SUM OF COST OF TECHNOLOGIES OF STATE
CALCULATE TOTAL COST OF STATE = SUM OF FUEL, OPERATING, FIXED, AND MISCELLANEOUS COST
PRINT STATE NO., KEY OF STATE
C
C
SET MAXIND = MAX. NO. OF STATES
CHOOSE A STATE J INDEX
SET NONDOM (J) = 0
CHOOSE ANOTHER STATE I INDEX
I = J?
NO
YES
COST (I) > COST (J) ?
NO
YES
CHOOSE A POLLUTANT K
EMIS (I, K) > EMIS (J, K) ?
NO
YES
D
D
SET NONDOM(S) = 1 J IS NONDOMINANT, I.E., THERE EXISTS A STATE THAT COST LESS AND HAS LESS EMISSIONS
SEARCH SOURCES TO FIND MAX AND MIN EMISSIONS FOR EACH POLLUTANT
PRINT SOURCE NO., NO. OF STATES OF NONDOMINANT STATES, FOR EACH STATE THE TECHNOLOGIES AND LEVEL IN STATE, WHETHER THE STATE IS DOMINANT
END

```
      PROGRAM SORT III
C
C     NTDIM = NO. OF TECHNOLOGIES DIMENSIONED (T)
C     NSDIM = NO. OF     STATES    DIMENSIONED (S)
C     NPDIM = NO. OF  POLLUTANTS  DIMENSIONED (P)
C
C     ARRAY DIMENSIONS ARE BASEMIS(P),NOGO(T,T),MOM(34),NOPLEV(9),
C     NCODE(T),REDUC(T,9,P),KBAS(T),     LEV(T),KEY(S),COST(S),FRED(P),
C     EMIS(S,P),NONDOM(S),TEMP1(P),BOTEMIS(P),EMISRNG(P),ISORT(S),
C     ITEMP1(P),COSTLV(T,9,12),COSTST(S,6),ISORT(S,P)
C
      DIMENSION BASEMIS(5), NOGO(10,10), MOM(34), NOPLEV(10), NCODE(10)
     1   REDUC(10,9,5), KBAS(10),       LEV(10), KEY(100 ), COST(100 ),
     2   FRED(5), EMIS(100 ,5),NONDOM(100 ), TEMP1(5), BOTEMIS(5),
     3   EMISRNG(5),ISORT(100,5),ITEMP1(5),NSTATE(100), TNAM(10,9,4),
     4   SNAM(100,30),COSTLV(10,9,12), COSTST(100,6),RCT(6)
      NTDIM=10
      NSDIM=100
                              NPDIM=5
      NUMPOL=2
C
C     READ INPUT DATA
C
      IF (NUMPOL.GT.NPDIM) GO TO 141
      READ 31, KEY1,KEY2
   31 FORMAT (20I4)
      REWIND 12
      IF (KEY2.EQ.0) GO TO 1
      DO 2 LT=1,KEY2
      CALL SKIPFILE (12)
    2 CONTINUE
    1 CONTINUE
      READ 33, NTECH,(NOPLEV(J),J=1,10),(NCODE(J),J=1,10),KEYBASE,
     1       (MOM(I),I=1,18), KONTIN,NSRC,NCARD
   33 FORMAT (1X,I2,20I1,I10,18I2,I1,2X,I6,I2)
      IF(EOF,60) 175,30
   30 IF (NCARD.NE.9) GO TO 147
      IF (NTECH.GT.NTDIM) GO TO 142
      JIFFY=100*NSRC+10
      DO 63, I=1,NTECH
      DO 63, J=1,NTECH
   63 NOGO(I,J) = 0
      DO 65 I=1,33,2
      IF(MOM(I).LE.0) 66,68
   68 N1 = MOM(I)
      N2 = MOM(I+1)
      NOGO(N1,N2)=1
   65 NOGO(N2,N1)=1
C    INSERT KONTIN
   66 CONTINUE
      DO 76 N=1,NTECH
      KBAS(N)=KEYBASE/(10**N)
      KBAS(N)=(KEYBASE-KBAS(N)*10**N)/(10**(N-1))
   74 MM=NOPLEV(N)
      DO 76 M=1,MM
   73 READ 77, A,B,I,C,D,E,J,F,G,H,(TNAM(N,M,L),L=1,3),NN,MMH,IFFY
   77 FORMAT (1X,2F7.2,2(I1,3F6.2),3A4,3X,2I2,I5)
      IF (NN.NE.N.OR.MMM.NE.M ) GO TO 147
      IF (IFFY.NE.JIFFY) GO TO 147
      NC=NCODE(N)
      REDUC(N,M,1)=A
      REDUC (N,M,2)=B
C
C             THIRD SUBSCRIPT OF COSTLV IS
C                 FUEL OPR  FXD  MISC
C         IO       5     6    7    8
C         MID      1     2    3    4
C         HI       9    10   11   12
C
      DO 75 IF=1,12
   75 COSTLV(N,M,IF)=0.0
      IF (I.LE.0) GO TO 220
      COSTLV(N,M,I+4)=C
      COSTLV(N,M,I  )=D
      COSTLV(N,M,I+8)=E
  220 IF (J.LE.0) GO TO 225
      COSTLV(N,M,J+4)=F
      COSTLV(N,M,J  )=G
      COSTLV(N,M,J+8)=H
  225 CONTINUE
   76 CONTINUE
      DO 83 N=1,NTECH
      MM=NOPLEV(N)
      DO 83 M=1,MM
      TEMPA=0.0
      TEMPB=0.0
      DO 84 K=1,4
      TEMPA=TEMPA+(COSTLV(N,M,K)-COSTLV(N,M,K+4))**2
   84 TEMPB=TEMPB+(COSTLV(N,M,K)-COSTLV(N,M,K+8))**2
      COSTLV(N,M,5)=TEMPA
   83 COSTLV(N,M,6)=TEMPB
C
C     COMPUTE STATES
C
      IF (NTECH.EQ.NTDIM) GO TO 50
   81 N=NTDIM-NTECH
   42 DO 43 J=1,N
      K=NTECH+J
      NCODE(K)=1
   43 NOPLEV(K)=1
   50 NJM=0
      N1 =NOPLEV(1 )
      N2 =NOPLEV(2 )
      N3 =NOPLEV(3 )
      N4 =NOPLEV(4 )
      N5 =NOPLEV(5 )
      N6 =NOPLEV(6 )
      N7 =NOPLEV(7 )
      N8 =NOPLEV(8 )
      N9 =NOPLEV(9 )
      N10=NOPLEV(10)
      DO 60 J1 =1,N1
      LEV(1 )=J1
      DO 60 J2 =1,N2
      LEV(2 )=J2
      DO 60 J3 =1,N3
      LEV(3 )=J3
      DO 60 J4 =1,N4
      LEV(4 )=J4
      DO 60 J5 =1,N5
      LEV(5 )=J5
      DO 60 J6 =1,N6
      LEV(6 )=J6
      DO 60 J7 =1,N7
      LEV(7 )=J7
      DO 60 J8 =1,N8
      LEV(8 )=J8
      DO 60 J9 =1,N9
      LEV(9 )=J9
      DO 60 J10=1,N10
      LEV(10)=J10
      DO 53 J=1,NTECH
      DO 53 K=1,NTECH
      IF ((LEV(J)-1)*(LEV(K)-1)*NOGO(J,K)) 53,53,60
   53 CONTINUE
      NUM=NUM+1
      KEY(NUM)=0
      COST(NUM)=0.0
      DO 56 IF=1,6
   56 COSTST(NUM,IF)=0.0
      DO 91 K=1,NUMPOL
   91 EMIS(NUM,K)=0.0
      DO 59 J=1,NTECH
      K=LEV(J)
      GO TO (54,57),NCODE(J)
   54 DO 92 N=1,NUMPOL
   92 EMIS(NUM,N)=EMIS(NUM,N)+REDUC(J,K,N)
      GO TO 58
   57 DO 11 N=1,NUMPOL
      IF (EMIS(NUM,N).GT.0.0) GO TO 12
   11 CONTINUE
      NUM=NUM-1
      GO TO 60
   12 DO 93 N=1,NUMPOL
   93 EMIS(NUM,N)=EMIS(NUM,N)*(1.0-REDUC(J,K,N)/100.0)
   58 DO 61 IF=1,6
   61 COSTST(NUM,IF)=COSTST(NUM,IF)+COSTLV(J,K,IF)
      KF=3*(J-1)
      DO 55 KG=1,3
   55 SNAM(NUM,KG+KF)=TNAM(J,K,KG)
   59 KEY(NUM)=KEY(NUM)+K*10**(J-1)
      IF (NSRC.LE.12) GO TO 166
      IF (NCODE(NTECH).EQ.2) GO TO 166
      IF (NTECH.EQ.1) GO TO 166
      DO 64 N=1,NUMPOL
      IF (EMIS(NUM,N).GT.0.0) GO TO 166
   64 CONTINUE
      NUM=NUM-1
      GO TO 60
  166 CONTINUE
      DO 62 IF=1,4
   62 COST(NUM)=COST(NUM)+COSTST(NUM,IF)
      IF (KEY(NUM).NE.KEYBASE) GO TO 10
      NUMBAS=NUM
      DO 96 K=1,NUMPOL
      BASEMIS(K)=EMIS(NUM,K)
   96 CONTINUE
   10 IF (KEY1) 97,97,99
   99 WRITE (61,98) NUM, KEY(NUM)
   98 FORMAT (10X, I5, I15)
   97 CONTINUE
   60 CONTINUE
      MAXIND=NUM
      IF (MAXIND.GT.NSDIM) GO TO 145
C
C     SET NONDOM(J)=1,IF J IS NONDOMINANT
C
      NDOM=0
      DO 102 J=1,MAXIND
      NONDOM(J) = 0
      DO 100 I=1,MAXIND
      IF (I.EQ.J) GO TO 100
      IF (COST(I).GT.COST(J)) GO TO 100
      DO 101 K=1, NUMPOL
      IF (EMIS (I,K).GT.EMIS (J,K)) GO TO 100
  101 CONTINUE
      NONDOM(J)=1
      NDOM=NDOM+1
      GO TO 103
  100 CONTINUE
  103 IF (J.EQ.NUMBAS) NONDOM(J)=NONDOM(J)+2
  102 CONTINUE
C
C     SEARCH SOURCES TO FIND MAX AND MIN EMISSIONS FOR EACH POLLUTANT,
C     MIN IS BOTEMIS(K),MAX-MIN IS EMISRNG(K)
C
      DO 112 K=1,NUMPOL
      TEMP1(K) = 0.0
                        BOTEMIS(K) = 100000.
      DO 111 I=1,MAXIND
      IF (EMIS(I,K).GE.TEMP1(K)) TEMP1(K) = EMIS(I,K)
      IF (EMIS(I,K).LE.BOTEMIS(K)) BOTEMIS(K) = EMIS(I,K)
  111 CONTINUE
  112 EMISRNG(K) = TEMP1(K) - BOTEMIS(K)
C
C     DETERMINE ISORT(I,K)
C
      DO 121 I=1,MAXIND
      DO 122 K=1,NUMPOL
      TEMPC = EMISRNG(K)/10.0
      DO 123 N=1,10
      TEMPA = TEMPC*FLOAT(N)
      TEMPB = EMIS(I,K)-BOTEMIS(K)
      IF (TEMPB.LE.TEMPA) GO TO 122
  123 CONTINUE
      N = 10
  122 ISORT(I,K) = N-1
  121 CONTINUE
C
C     DETERMINE NSTATE
C
      NIX=MAXIND-NDOM+NONDOM(NUMBAS)/2
      DO 200 I=1,MAXIND
  200 NSTATE(I)=0
      DO 205 J=1,NIX
      BIG=10.0**300
      DO 201 I=1,MAXIND
      IF (NONDOM(I).EQ.1) GO TO 201
      IF (NSTATE(I).NE.0) GO TO 201
      IF (COST(I).GT.BIG) GO TO 201
      NSAV=I
      BIG=COST(I)
  201 CONTINUE
      NSTATE(NSAV)=J
  205 CONTINUE
C
C    REVISE COST
C
      RC=COST(NUMBAS)
      DO 230 J=1,6
  230 RCT(J)=COSTST(NUMBAS,J)
      DO 235 I=1,MAXIND
      COST(I)=COST(I)-RC
      DO 240 J=1,4
  240 COSTST(I,J)=COSTST(I,J)-RCT(J)
      DO 235 J=5,6
  235 COSTST(I,J)=SQRT(COSTST(I,J)+RCT(J))
      DO 245 J=5,6
  245 COSTST(NUMBAS,J)=SQRT(RCT(J))
C
C    OUTPUT
C
      WRITE (12,137) NSRC,NTECH,MAXIND,NIX
  137 FORMAT (1H1,10I7)
      KG=3*NTECH
      DO 131 I=1,MAXIND
      DO 132 K=1,NUMPOL
  132 ITEMP1(K)=((1.0-EMIS(I,K)/BASEMIS(K))*100.0)+0.5
      PUNCH 133,      NSRC,KEY(I),NSTATE(I), (ISORT(I,K),K=1,5),NONDOM(I)
     1  , COST(I),(ITEMP1 (K),K=1,NUMPOL)
  133 FORMAT (I7,I12,I4, 2X, 2I1, I3,F7.0, 1X,  2I4)
      WRITE (12,134) KEY(I),NSTATE(I),(ISORT(I,K),K=1,NUMPOL),NONDOM(I),
     1    (EMIS(I,M),M=1,NUMPOL),COST(I),(COSTST(I,IF),IF=1,6),
     2                                  (SNAM(I,N),N=1,KG)
  134 FORMAT(1H0,I12,I3,2X,2I1,2X,I1,2X,2E12.5/1X,7F12.5/1X,30A4)
  131 CONTINUE
      ENDFILE 12
      N=MAXIND-NDOM
      PRINT 136,      MAXIND,N,NDOM, NSRC
  136 FORMAT (2H0 ,4I15)
      GO TO 1
C
C    ERROR MESSAGES
C
  141 WRITE (61,143)
  143 FORMAT (1H1///10X, *ERROR NUMPOL,GT,NPDIM*)
      STOP
  142 WRITE (61,144)
  144 FORMAT (1H1///10X, *ERROR NTECH,GT,NTDIM*)
      GO TO 1
  145 WRITE (61,146) MAXIND
  146 FORMAT (1H1///10X, *MAXIND EQUALS* I7)
      GO TO 1
  147 WRITE (61,148) NSRC
  148 FORMAT (5X, 13HBAD CARD READ  I8)
      GO TO 1
  175 STOP
      END
```

SORTCON

The SORTCON program selects one emission control state for each source and then computes the total concentration and costs resulting from all the sources in their selected states. Output of the MET program and the SORT program form the input to this program. For each selected state SORTCON then computes the resulting concentration of the pollutants at each receptor point due to the individual source. The concentrations due to each source in the selected states are then summed to obtain the total concentration due to all sources. SORTCON also sums the cost to each source to obtain the cost and the fuel, operating, fixed miscellaneous, and total.

SORTCON PROGRAM FLOW CHART


START SORTCON
READ NO. OF AGGREGATE AREA SOURCES, NO. OF POINT SOURCES, NO. OF POLLUTANTS, NO. OF RECEPTOR POINTS
TOTAL NO. OF SOURCES = NO. OF AGGREGATE AREA SOURCES AND NO. OF POINT SOURCES
READ NO. OF STATES FOR EACH SOURCE
A
A
CHOOSE A SOURCE
CALL SORT TAPE
SORT TAPE GIVES SOURCE NO., NO. OF TECHNOLOGIES AVAILABLE TO SOURCE, AND FOR EACH STATE - THE KEY TO THE STATE - KEY, WHETHER THE STATE IS DOMINATED BY ANY OTHER STATE - NONDOM EMIS(M), RATE OF EMISSION OF POLLUTANT M, TOTAL COST OF STATE; AND FUEL, OPERATING, FIXED, AND MISCELLANEOUS COST
CALL MET TAPE
MET TAPE GIVES
COVE(L) = CONCENTRATION AT RECEPTOR PT. L / EMISSION RATE OF SOURCE
B
B
CHOOSE A POLLUTANT M INDEX
CHOOSE A RECEPTOR POINT L INDEX
CALCULATE CONCENTRATION OF POLLUTANT M AT RECEPITOR PT. L FROM SOURCE - CONTOT (M, L)
CONTOT (M, L) = EMIS (M) X COVE(L)
GO TO A
CALCULATE TOTAL CONCENTRATION OF POLLUTANT M AT RECEPTOR PT. L = SUM OF CONCENTRATIONS FROM ALL SOURCES
C
C
CALCULATE TOTAL COST, FUEL COST, OPERATING COST, FIXED COST, MISCELLANEOUS COST = SUM OF COST FROM ALL SOURCES
PRINT COSTS, CONCENTRATION FOR EACH POLLUTANT AT EACH RECEPTOR POINT
END

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```
      PROGRAM SORTCON2
      DIMENSION SSTATE(175),RATIO(10),COVE(100),CONCNT(10,100)
      DIMENSION EMIS(10),EMSTOT(10),CONTOT(10,100),EMIP(10),ISORT(2),
     1    SNAM(30),TITLE(20)
      EQUIVALENCE (SORP,SOPR)
      INTEGER SSTATE
      RATIO(1)=2.7083
      RATIO(2)=0.001'
   10 READ(60,11) NOUSE,NUMPTS,NUMPOL,NRECEP
   11 FORMAT(4I5)
C     NUMPTS=TOTAL NUMBER OF POINT SOURCES
C     NOUSE=TOTAL NUMBER OF AGGREATE AREA SOURCES
C     KC=TOTAL NUMBER OF SOURCES(POINT AND AGGREATE)
C     SSTATE=STATE FOR EACH SOURCE IN NUMERICAL ORDER
C     NRECEP=TOTAL NUMBER OF RECEPTOR POINTS
C     NUMPOL=TOTAL NUMBER OF POLLUTANT TYPES
   15 KC=NOUSE+NUMPTS
C     GO TO 22
   20 READ 16, (TITLE(I),I=1,20)
   16 FORMAT (20A4)
      IF (EOFCKF(60).EQ.1) 999,22
   22 READ(60,21)(SSTATE(L),L=1,KC)
   21 FORMAT(20I4)
      TCOST =0.
      TSFUEL=0.
      TSORP =0.
      TSFXD =0.
      TSMISC=0.
      TLOVP =0.
      THIVP =0.
      PRINT 12,(TITLE(I),I=1,20)
   12 FORMAT (1H1,///20A4)
    2 DO 6 I=1,NUMPOL
    3 DO 6 J=1,NRECEP
    4 CONCNT(I,J)=0.
    6 CONTINUE
C     III=SOURCE NUMBER(AREA OR POINT SOURCE)IN NUMERIC SEQUENCE
C     NSRC=SOURCE NUMBER IN EITHER TWO DIGIT OR SIX DIGIT CODE
      III=0
   30 DO 98 III=1,KC
   47 READ (13,48) NSRC,NTECH
   48 FORMAT (1X,3I7)
      KG=3*NTECH
   50 READ (13,134 ) KEY,NSTATE,(ISORT(K),K=1,NUMPOL),NONDOM,
     1    (EMIS(M),M=1,NUMPOL) ,
     2                COST,SFUEL,SOPR,SFXO,SMISC,SVARLO,SVARHI,(SNAM(N),N
     3    =1,KG)
C  53 IF (NONDOM.LT.2)50,58
   53 IF(NSTATE.NE.SSTATE(III)) 50,58
   58 IF (NOUSE+1-III) 80,74,60
   74 READ (25,73) DUMMY
   73 FORMAT (A1)
      IF (EOFCKF(25).EQ.1) 80,74
C     NOW CALCULATE CONCENTRATIONS FOR AREA SOURCES/POLLUTANT/RECEPTOR
C     LET M=THE RANGE OF THE POLLUTANTS
C     LET L=THE RANGE OF THE RECEPTOR POINTS
   60 READ INPUT TAPE 25,61,LINE,(EMSTOT(M),(CONTOT(M,L),L=1,NRECEP),M=1
      1.NUMPOL)
   61 FORMAT(I5./(8E13.5/))
C     IF(LINE.EQ.III) GO TO 65



      IF(LINE.EQ.III) 65,63
   63 WRITE(61.64)
   64 FORMAT(1H1,///22H      ERROR LINE.NE.III)
   65 DO 79 MM=1.NUMPOL
   70 DO 79 LL=1,NRECEP
      CONTOT(MM.LL)=CONTOT(MM,LL)*EMIS(MM)
      CONCNT(MM.LL)=CONCNT(MM.LL)+CONTOT(MM.LL)
   79 CONTINUE
      GO TO 101
   80 READ INPUT TAPE 25.81.NUM.(EMIP(M).M=1.NUMPOL),(COVE(L),L=1.NRECEP
     1)
   81 FORMAT(A1./(8E13.5/))
   85 DO 89 MM=1.NUMPOL
      TEMP1=EMIS(MM)*RATIO(MM)
   86 DO 89 LL=1.NRECEP
      CONTOT(MM.LL)=TEMP1*COVE(LL)
      CONCNT(MM.LL)=CONCNT(MM.LL)+ CONTOT(MM.LL)
   89 CONTINUE
  101 CONTINUE
C     THE TOTAL CONCENTRATIONS$CONCNT(M,L)$ARE NOW CALCULATED FOR EACH
C     SOURCE AND ARE SUMMED BY POLLUTALT TYPE(M) AND RECEPTOR POINT(L)
      TCOST=TCOST+COST
      TSFUEL=TSFUEL+SFUEL
      TSORP=TSORP+SORP
      TSFXD=TSFXD+SFXD
      TSMISC=TSMISC+SMISC
      THIVP=THIVP+(SVARHI)**2
      TLOVP=TLOVP+(SVARLO)**2
      PRINT 49,    NSRC.NTECH
   49 FORMAT(1H0,3I7)
C  49 FORMAT(1H1.3I7)
      PRINT 134,      KEY,NSTATE,(ISORT(K),K=1.NUMPOL),NONDOM.
     1   (EMIS(M),M=1.NUMPOL) ,
     2                COST.SFUEL,SOPR,SFXD,SMISC.SVARLO,SVARHI,(SNAM(N).N
     3      =1,KG)
  134 FORMAT(1X. I12,I3,2X,2I1,2X,I1.2X,2E12.5/
     1         1X,7E12.5/1X.30A4)
C     DO 135 MM=1,NUMPOL
C     PRINT 136, (CONTOT(MM.LL), LL=1,NRECEP)
C 135 CONTINUE
  136 FORMAT (/6(/3X,10E13.5))
  124 READ (13, 73) DUMMY
      IF (EOFCKF(13).EQ.1) 98,124
   98 CONTINUE
      TLOV=SQRTF(TLOVP)
      THIV=SQRTF(THIVP)
      PRINT 1343,TCOST,TSFUEL,TSORP,TSFXD,TSMISC.TLOV,THIV
 1343 FORMAT(///1X,7E12.5)
      PRINT 12,(TITLE(I),I=1,20)
      PRINT 140, ((L,CONCNT(1,L),CONCNT(2,L)),L=1.51)
  140 FORMAT (     /// 51(/I5.2F20.5))
      REWIND 13
      REWIND 25
      GO TO 20
  999 STOP
```

INTCODE

There are N sources of emission, each source emitting k different kinds of pollution. The n-th source has S(n) different control states (including the present state) which cost C(n,s)(n = 1,..,N; s = 1,..,S(n)), where C(n,s) is the cost of the s-th state of the n-th source. The emissions from the s-th state of the n-th source is E(n,s,k) (n = 1,..n; s = 1,..S(n); k = 1,..,K) for the k-th pollutant. Furthermore, M receptor points have been specified at different locations in the area of interest. With the use of the appropriate meteorological diffusion model, we compute the matrix A(n,s,k,m)(n = 1,..N; s = 1,..S(n); k = 1,..K; m = 1,..M), which is the concentration of the k-th pollutant at the m-th receptor due to emissions from the n-th source in the s-th state.

INTCODE is formulated mathematically as follows:

$$(1) \quad \text{Minimize cost} = \sum_{n=1}^{N} \sum_{s=1}^{S(n)} C(n,s)\ X(n,s)$$

subject to:

$$(2) \quad \sum_{n-1}^{N} \sum_{s=1}^{S(n)} E(n,s,k)\ X(n,s) \leq B(k) \qquad (k=1,\ldots,K)$$

$$(3) \quad \sum_{s=1}^{S(n)} X(n,s) = 1 \qquad (n=1,\ldots,N)$$

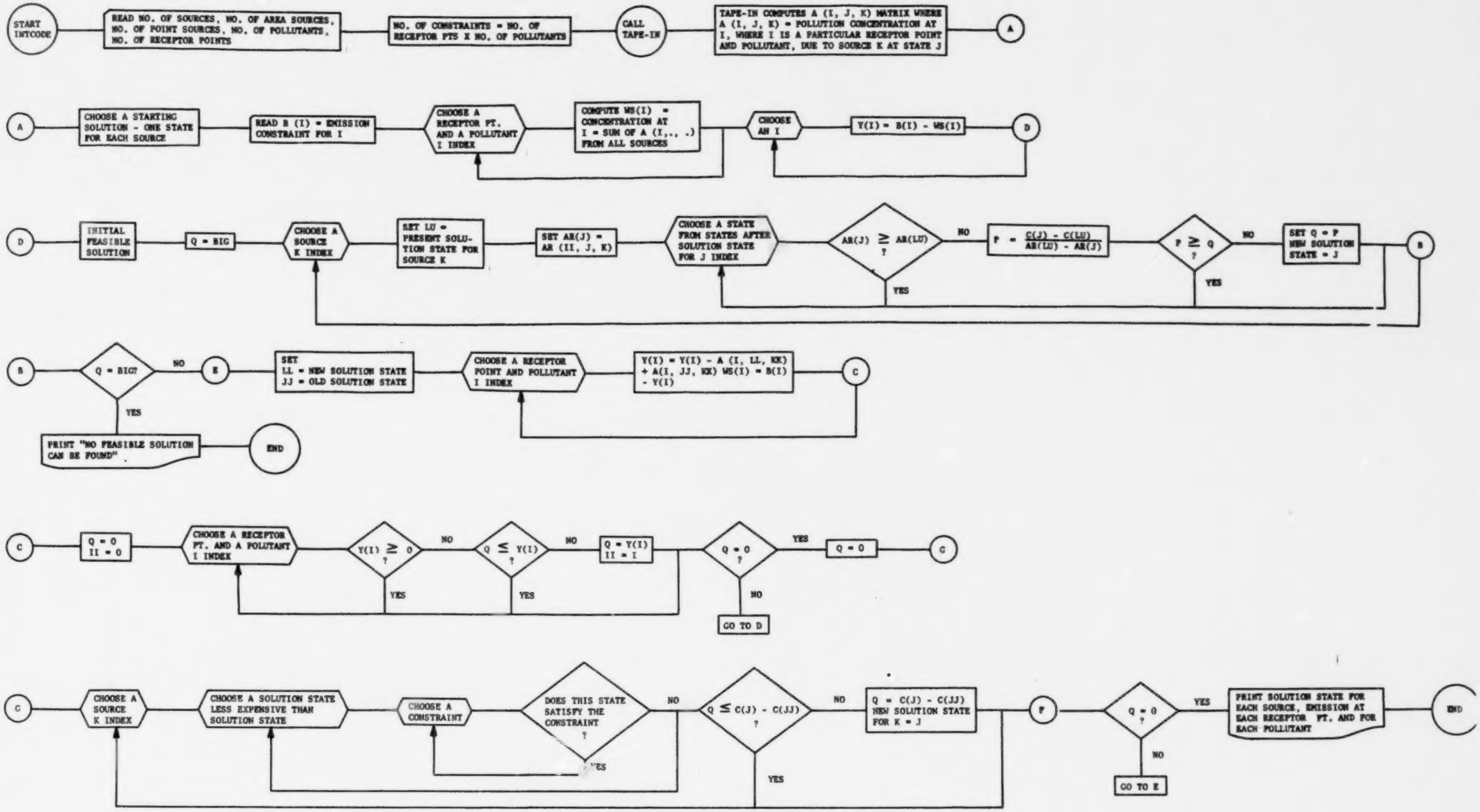
and X(n,s) can take on values of zero or one only. This problem states that costs are to be minimized in such a way that the total emissions of each pollutant do not exceed a given amount B(k).

The set of equations (2) can be replaced by

$$\sum_{N=1}^{N} \sum_{x=1}^{S(n)} A(n,s,k,m)\ X(n,s) \leq B(k), \quad (m=1,..,M;\ k=1,..,K)$$

which states that the total concentration of any pollutant at any receptor point cannot exceed a given amount B'(k).

INTCODE PROGRAM FLOW CHART


START INTCODE
READ NO. OF SOURCES, NO. OF AREA SOURCES, NO. OF POINT SOURCES, NO. OF POLLUTANTS, NO. OF RECEPTOR POINTS
NO. OF CONSTRAINTS = NO. OF RECEPTOR PTS X NO. OF POLLUTANTS
CALL TAPE-IN
TAPE-IN COMPUTES A (I, J, K) MATRIX WHERE A (I, J, K) = POLLUTION CONCENTRATION AT I, WHERE I IS A PARTICULAR RECEPTOR POINT AND POLLUTANT, DUE TO SOURCE K AT STATE J
A
A
CHOOSE A STARTING SOLUTION - ONE STATE FOR EACH SOURCE
READ B (I) = EMISSION CONSTRAINT FOR I
CHOOSE A RECEPTOR PT. AND A POLLUTANT I INDEX
COMPUTE WS(I) = CONCENTRATION AT I = SUM OF A (I,., .) FROM ALL SOURCES
CHOOSE AN I
Y(I) = B(I) - WS(I)
D
D
INITIAL FEASIBLE SOLUTION
Q = BIG
CHOOSE A SOURCE K INDEX
SET LU = PRESENT SOLUTION STATE FOR SOURCE K
SET AR(J) = AR (II, J, K)
CHOOSE A STATE FROM STATES AFTER SOLUTION STATE FOR J INDEX
AR(J) ≥ AR(LU) ?
NO
YES
P = C(J) - C(LU) / AR(LU) - AR(J)
P ≥ Q ?
NO
YES
SET Q = P NEW SOLUTION STATE = J
B
B
Q = BIG?
NO
YES
E
SET LL = NEW SOLUTION STATE JJ = OLD SOLUTION STATE
CHOOSE A RECEPTOR POINT AND POLLUTANT I INDEX
Y(I) = Y(I) - A (I, LL, KK) + A(I, JJ, KK) WS(I) = B(I) - Y(I)
C
PRINT "NO FEASIBLE SOLUTION CAN BE FOUND".
END
C
Q = 0 II = 0
CHOOSE A RECEPTOR PT. AND A POLUTANT I INDEX
Y(I) ≥ 0 ?
NO
YES
Q ≤ Y(I) ?
NO
YES
Q = Y(I) II = I
Q = 0 ?
YES
NO
Q = 0
G
GO TO D
G
CHOOSE A SOURCE K INDEX
CHOOSE A SOLUTION STATE LESS EXPENSIVE THAN SOLUTION STATE
CHOOSE A CONSTRAINT
DOES THIS STATE SATISFY THE CONSTRAINT ?
NO
YES
Q ≤ C(J) - C(JJ) ?
NO
YES
Q = C(J) - C(JJ) NEW SOLUTION STATE FOR K = J
F
Q = 0 ?
YES
NO
GO TO E
PRINT SOLUTION STATE FOR EACH SOURCE, EMISSION AT EACH RECEPTOR PT. AND FOR EACH POLLUTANT
END

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```
      PROGRAM INTCODE
C     BALINTFY ZERO-ONE LP ALGORITHM FOR THE MULTIPLE CHOICE STRUCTURE
C
C
C     OBJECTIVE FUNCTION TO BE MONOTONE NON-DECREASING OVER EACH CHOICE
C      CLASS
C
C     CONSTRAINTS TO BE OF ) OR = FORM
C
C     DIMENSION A(TOTAL NO, ROWS - EXCLUSIVE OF MULTIPLE CHOICE CON-
C      STRAINTS, MAX. NO. OF VARIABLES IN CLASS),MC(NO. OF CLASSES),
C      MB(NO. OF CLASSES),ME(NO, OF CLASSES),AR(TOTAL NO. OF VARIABLES);
C      B(TOTAL NO, OF ROWS-EXCLUSIVE OF MULTIPLE CHOICE CONSTRAINTS),
C      Y(TOTAL NO. OF ROWS-EXCLUSIVE OF MULTIPLE CHOICE CONSTRAINTS),
C      C(TOTAL NO, OF VARIABLES)
C
C     INPUT PARAMETERS .......
C     KC=TOTAL NO, OF CLASSES
C     M=TOTAL NO, OF ROWS (EXCLUSIVE OF MULTIPLE CHOICE CONSTRAINTS)
C     KPR= PRINT PARAMETER
C     MC= LAST SUBSCRIPT IN EACH CLASS (J)
C     C(J)= COST COEFFICIENTS
C     B(I)= REQUIREMENTS VECTOR
C     A(I,J)= ACTIVITY MATRIX (INPUT BY CHOICE CLASS)
C     **********
      COMMON/A/NOUSE,EMSTOT(2),CONTOT(12,2,60),NRECEP,NUMPOL,NUMPTS,
     1   EMIP(2),COVE(150,60),EMIS(2),MC(200),C(1000),EMIT(1000,2),
     2    FIND(1000),RATIO(2),MP(200),MR(200),KC,KONUM
      DIMENSION MB(200),ME(200),AR(1000),B(600),Y(600),WS(600),
     1   SOLUT(200),MSTART(200)
      EQUIVALENCE (M,KONUM)
  100 FORMAT(8I10)
  101 FORMAT(8F10.2)
  102 FORMAT(6X, 11HPROBLEM NO,,I5/6X, 17HSTARTING SOLUTION   /)
  103 FORMAT(6X, 20HACTIVITY MATRIX HAS ,I3,10H ROWS AND ,
     1 I3, 8H COLUMNS /)
  106 FORMAT(6X, 24HNO, OF CHOICE CLASSES = ,  I4 /    )
  107 FORMAT (///6X, 13HITERATION NO,I10,10X,21HOBJECTIVE FUNCTION = ,
     1     E15.7)
  108 FORMAT(/6X,26HVALUES OF CONSTRAINTS ARE-     / (10E12.4))
  109 FORMAT (20I4)
  199 FORMAT(6X,41HNEAR-OPTIMAL SOLUTION AFTER ITERATION NO.,
     1 I6/)
  275 FORMAT (1H0, 5X, 5HCLASSI5,5X,10HSOURCE NO, , I8, 5X,
     1      13HNO. OF STATES , I5, // 6X, 4HCOST)
  296 FORMAT(1H1,5X,30H****************************** /)
  297 FORMAT(6X,21HOBJECTIVE FUNCTION = ,F13.5 //)
  298 FORMAT(/6X,29HNON-ZERO COMPONENTS OF X ARE-    )
  299 FORMAT(1H0,5X,30H****************************** / )
  300 FORMAT (6X, 10E11.3)
C 398 FORMAT(1H0,5X,10I10//(6X,10I10/))
  599 FORMAT(1H0,5X,26HACTIVITY MATRIX BY CLASS -  /)
  850 FORMAT(6X,41HNO FEASIBLE SOLUTION CAN BE OBTAINED FOR ,
     1 10HCONSTRAINT,I2,12H, CLASS NO, ,I2  //6X,
     2 38HSOLUTION FAILS TO MEET REQUIREMENT BY ,F9.2 /)
  881 FORMAT(1H0,5X,22HREQUIREMENTS VECTOR -  /  )
```

```
  998 FORMAT (1H0,5X,6H INDEX,I3,2H K,I3)
  996 FORMAT (1H0,5X,6H KNDEX,I3,2H K,I3)
  995 FORMAT (1H0,5X,6H LNDEX,I3,2H K,I3)
  994 FORMAT (1H0,5X,6H MNDEX,I3,2H K,I3)
 1101 FORMAT (2I10)
 1102 FORMAT (8F10.3)
 1103 FORMAT (1H0,5X,8HA MATRIX   )
 1140 FORMAT(11H0      TIME , E18.10,10H MILLISEC,  /)
 1398 FORMAT(1H0,5X,10F11.2//(6X,10F11.2/))
C      **********
       TIME1=TIMEF(X)
       NP=1
       BIG=10.0**300
C      **********
       READ  109, INSW,KPR,ITNUM
       PRINT 109, INSW,KPR,ITNUM
       IF (INSW.EQ.1) GO TO 4
       READ  109,KC,NOUSE,NUMPTS,NUMPOL,NRECEP
       PRINT 109,KC,NOUSE,NUMPTS,NUMPOL,NRECEP
       KONUM=NRECEP*NUMPOL
       READ  109, (MP(I),I=1,KONUM)
       PRINT 109, (MP(I),I=1,KONUM)
       READ  109, (MR(I),I=1,KONUM)
       PRINT 109, (MR(I),I=1,KONUM)
       READ  101, (RATIO(I),I=1,NUMPOL)
       PRINT 300, (RATIO(I),I=1,NUMPOL)
       CALL TAPEIN
       GO TO 1
    4  READ (22) CONTOT,COVE,MC,C,EMIT,FIND,KC,NOUSE,NUMPTS,NUMPOL,
     1    NRECEP,KONUM,MP,MR,RATIO
    1  READ  109, (MSTART(K),K=1,KC)
       IF(EOF,1) 99,63
   63  CONTINUE
       PRINT 296
       PRINT 102, NP
       PRINT 109, (MSTART(K),K=1,KC)
       READ  101, (B(I),I=1,KONUM)
       TIME2=TIMEF(X)-TIME1
       WRITE ( 3,1140) TIME2
    5  CONTINUE
       N=MC(KC)
       WRITE(3,103) M,N
       WRITE(3,299)
C      **********
C      INITIAL SOLUTION
       Z=0.
       IT=0
       LL=0
       DO 1135 I=1,M
 1135  WS(I)=0.0
   53  DO 36 K=1,KC
       NY=MSTART(K)
       L=LL+1
       LL=MC(K)
       NL=LL-L+1
       M3(K)=L+NY-1

       NX=NY+L-1
       Z=Z+C(NX)
       DO 35 I=1,M
   35  WS(I)=WS(I)+A(I,NY,K)
   36  CONTINUE
       TIME2=TIMEF(X)-TIME1
       WRITE ( 3,1140) TIME2
```

```
      DO 1136 I=1,M
 1136 Y(I)=B(I)-WS(I)
      IF (KPR.LT.3) GO TO 1121
      WRITE(3,881)
      WRITE(3,300)(B(I),I=1,M)
 1121 CONTINUE
      GO TO 64
C     ***********
C     INITIAL FEASIBLE SOLUTION
   39 Q=BIG
      WRITE ( 3,107) IT, Z
      LFB=IT/ITNUM
      IF (IT.NE.LFB*ITNUM) GO TO 1150
      TIME2=TIMEF(X)-TIME1
      WRITE ( 3,1140) TIME2
      WRITE ( 3,298)
      DO 1126 K=1,KC
      IM=MB(K)
 1126 SOLUT(K)=FIND(IM)
      WRITE(3,1398)(SOLUT(K),K=1,KC)
      WRITE ( 3,108)(WS(I), I=1,M)
 1150 CONTINUE
      IT=IT+1
      LL=0
      DO 55 K=1,KC
      K=K
      KL=LL+1
      LJ=MB(K)
      LL=MC(K)
      NL=LL-KL+1
      KKL=0
      DO 45 J=KL,LL
      KKL=KKL+1
      AR(J)=A(II,KKL,K)
   45 CONTINUE
      L=LU+1
      IF(L.GT.LL)GO TO 55
      DO 51 J=L,LL
      IF(AR(J).GE.AR(LU)) GO TO 51
      P=(C(J)-C(LU))/(AR(LU)-AR(J))
      IF EXPONENT FAULT 51, 1122
 1122 CONTINUE
      IF(P.GE.Q)GO TO 51
      Q=P
      ME(K)=J
      KK=K
   51 CONTINUE
   55 CONTINUE
      IF(Q.NE.BIG  )GO TO 59


      IF(Y(II).GE.0.) GO TO 196
      WRITE(3,296)
      WRITE(3,850) II,K,Y(II)
      GO TO 3009
   59 LL=ME(KK)
   60 JJ=MB(KK)
      Z=Z+C(LL)-C(JJ)
      IF(KK.LE.1) GO TO 654
      KKK=KK-1
      NL=MC(KK)-MC(KKK)
      LL=LL-MC(KKK)
      JJ=JJ-MC(KKK)
      GO TO 655
  654 NL=MC(1)
  655 IMC=KK
  649 CONTINUE
      DO 69 I=1,M
      Y(I)=Y(I)-A(I,LL,KK)+A(I,JJ,KK)
   69 WS(I)=B(I)-Y(I)
      MB(KK)=LL
      IF( KK.GT.1 ) MB(KK)=MB(KK)+MC(KKK)
C     SELECT MOST UNFEASIBLE CONSTRAINT
   64 Q=0.
      II =0
      DO 68 I=1,M
      IF(Y(I).GE.0.) GO TO 68
      IF(Q.LE.Y(I)) GO TO 68
      Q=Y(I)
      II=I
   68 CONTINUE
C     **********
C     NEAR-OPTIMAL SOLUTION
   70 IF(Q.NE.0.)GO TO 39
   72 Q=0.
      KL=0
   96 DO 93 K=1,KC
      IF(K.NE.1)GO TO 78
      L=1
      GO TO 79
   78 L=MC(K-1)+1
   79 JJ=MB(K)
      LU=JJ-1
      NL=MC(K)-L+1
      IF(LU.LT.L)GO TO 93
      DO 87 J=L,LU
      J=J
      KJ=J-L+1
      KJJ=JJ-L+1
      DO 85 I=1,M
      IF((Y(I)-A(I,KJ,K)+A(I,KJJ,K)).LT.0.) GO TO 87
   85 CONTINUE
      GO TO 89
   87 CONTINUE
      GO TO 93
   89 IF(Q.LE.(C(J)-C(JJ))) GO TO 93
      Q=C(J)-C(JJ)


      LL=J
      KK=K
   93 CONTINUE
   95 IF(Q.NE.0.)GO TO 60
C     **********
C     WRITE SOLUTION
  196 WRITE(3,296)
      WRITE(3,199)IT
      WRITE(3,297)Z
      TIME2=TIMEF(X)-TIME1
      WRITE ( 3,1140) TIME2
```

```
 3000 DO 1127 K=1,KC
      IM=MB(K)
      IF(K.EQ.1) GO TO 1127
      MB(K)=IM-MC(K-1)
 1127 SOLUT(K)=FIND(IM)
      WRITE(3.1398)(SOLUT(K),K=1,KC)
      PUNCH 109, (MB(K),K=1,KC)
      WRITE ( 3.108)(WS(I), I=1,M)
 3009 WRITE(3.299)
      NP=NP+1
      GO TO 1
   99 STOP
      END
```